



# Inner Basin Pipeline & Waterline Road **Reconstruction & Relocation Project**

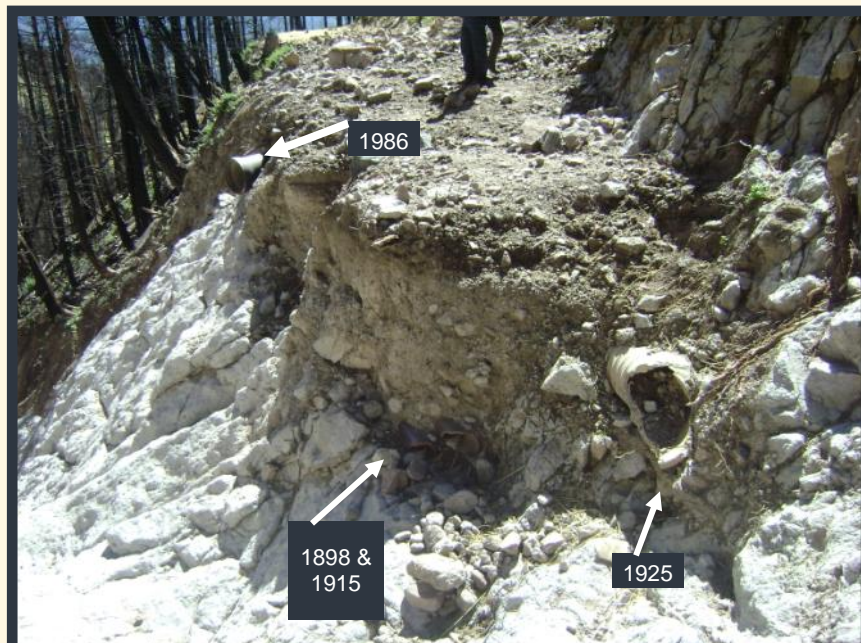
October 25, 2012





# History of the Pipeline

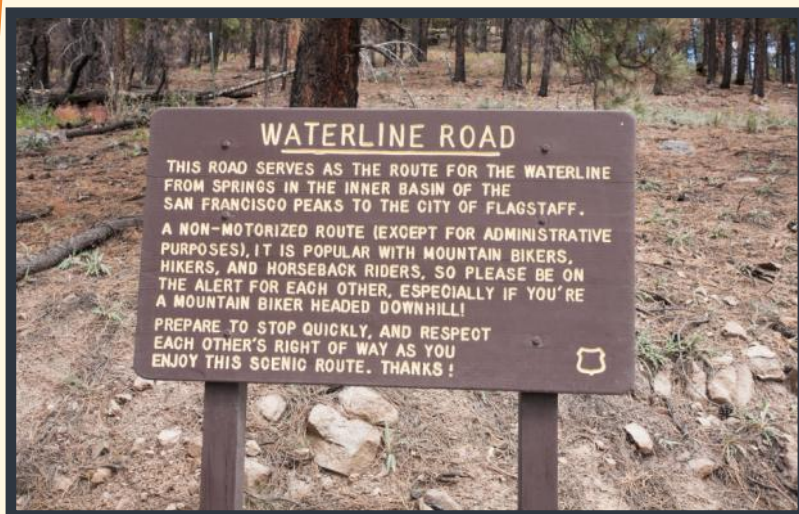
Since the founding of Flagstaff in 1882, City officials have sought to secure a safe, abundant, and reliable source of water for the community. The City first turned its attention to Jack Smith Spring in the Inner Basin of the San Francisco Peaks. In the spring of 1898 the City of Flagstaff solicited bids to construct a 6-inch vitrified clay pipeline from the Inner Basin to a 3 million gallon reservoir to hold the water, and the contractor was awarded in July of 1898. Work on the pipeline began the week of August 8, 1898 (Coconino Sun, 1898). The pipeline was hauled to the construction site by horse and installed in a hand-dug trench. In their November 19, 1898 edition, the Coconino Sun published an opinion article urging Flagstaff voters to approve an additional \$10,000.00 bond to cover expenses and costs needed to complete the pipeline project. In December, the bond was approved by a vote of 84 to 4, and the pipeline was completed. It then began delivering water from the spring at a rate of 150,000 gallons every 24 hours.



**PIPELINE HISTORY EXPOSED IN DRAINAGE—Sept. 9, 2010**  
All pipelines were severed at this location (Site 2) along Waterline Road following storms of the 2010 monsoon season. Photo: Mark Shiery, USDA Forest Service, Rocky Mountain Research Station

The system was improved again in 1914-1915 when the Santa Fe Railway Company began a second 8 inch vitrified clay pipeline from the Inner Basin to a new 50 million gallon storage reservoir. The contract for the new Inner Basin pipeline included construction of a 12-foot-wide access road along the pipeline.

In early April of 1925, the City Council decided to build a 15-inch concrete pipe water system and another 52 million gallon reservoir, which was finished mid November. The next upgrade was construction of the 12 million gallon North Reservoir Filtration Plant, near the old 50 MG reservoirs, in 1982.



## WATERLINE ROAD SIGN

Forest service sign provides explanation of the route and rules of the road. This is located near to where Waterline Road meets Schultz Pass road. Photo: Tom Alexander Photography

Starting in 1986, the City of Flagstaff began an ambitious multi-year project to improve the carrying capacity of the Inner Basin pipeline. The project involved systematically replacing the 15-inch concrete line with a 16-inch ductile iron pipeline (DIP). Approximately 8.5 miles of ductile iron pipe was laid between 1987 and 2006. The system is capable of providing 2 million gallons per day, and has delivered an average of 13% of the City's water supply over the last 60 years.

*2012 City of Flagstaff Report to Water Commission; Jacobs Engineering Group Inc., 2012*



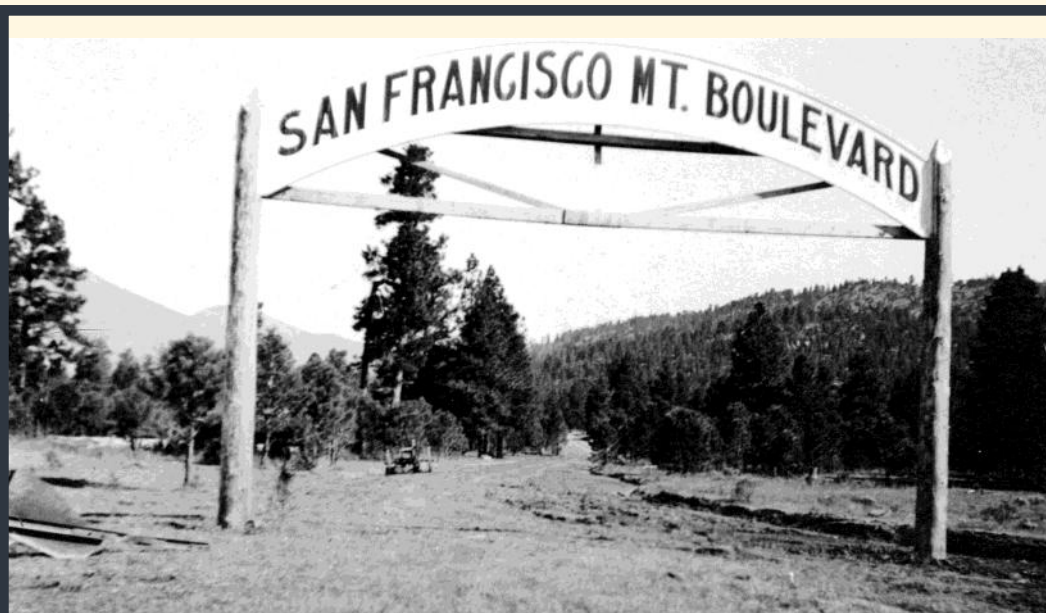
## EARLY CONSTRUCTION

Ca. 1898, workers mobilize pipe by horse and install in hand-dug trenches, in order to construct the 13-mile pipeline to a 3 million gallon reservoir. An 8-inch cast iron pipeline then continued into town, providing the railroad and 300 service connections with water. *Arizona Historical Society, Flagstaff* [AHS.0338.00005]



## BOOMING BUSINESS

Ca. 1890, water from local springs and, soon after, from the Inner Basin, was available to support the lumber and timber business. *Northern Arizona University, Cline Library* [NAU.PH.676.8]



## SCHULTZ PASS ROAD

Gateway sign to San Francisco Mt. Boulevard, now Schultz Pass Road, 1921. Location of this photograph is thought to be from near the City's North Reservoir Filtration Plant, in northwest Flagstaff. *Arizona Historical Society, Flagstaff* [AHS.0467.00075]



# Inner Basin Water Supply



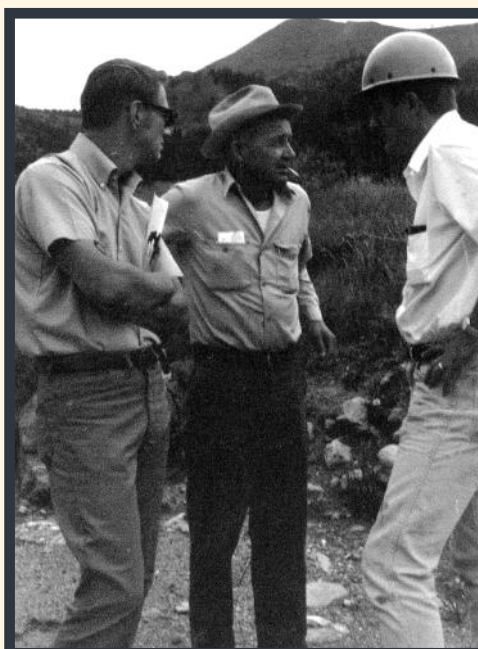
**INNER BASIN WELL HOUSE & SIGN**

Photos: Malcolm Alter, City of Flagstaff



**INNER BASIN WELL DRILLING (RIGHT)**

At right, Dale Bedenkopf, Consulting Civil Engineer, Jim Beard, Flagstaff Water Superintendent, and Sid Saunders, Chief of the Northern Arizona Field Office of the Bureau of Reclamation, discuss drilling of an Inner Basin well in 1967 or 1968 (photo courtesy of Sid Saunders)



Since 1898, the Inner Basin drinking water pipeline has provided a reliable summertime water source for the City of Flagstaff. This water source provides 20% of the City's peak day water supply in the summer months, and it is estimated that the cost of replacing this supply from other water sources is an extra \$6,000 per day. Without water from the Inner Basin, the City is primarily dependent on the Lake Mary Reservoir and ground water wells. The water wells require higher costs for pumping and Lake Mary is often a limited supply during dry years.

Between 1966 and 1971 thirteen cased wells were constructed in the Inner Basin. Eight were exploration holes and five were constructed to produce water for the Flagstaff system. Flagstaff currently pumps from three of these wells during the summer months. Pumps are line shaft turbine units powered by diesel engines.

The City has filed

Statement of Claims for legal water rights to surface water within the San Francisco Peaks & Inner Basin, totaling

approximately 1,619 acre-feet per year. Between the 1890s and 1961 seven large springs were developed from perched groundwater aquifers for the Flagstaff system.

Water from the Inner Basin is delivered by gravity to the North Reservoir Filtration Plant (shown at right) 2,000 feet below in elevation, located at the base of Schultz Pass Road near Highway 180. At the City's North RFP, the water is filtered, disinfected with chlorine and then exposed to ultraviolet radiation that kills harmful, disease-causing bacteria that may be present in the water. Water from this plant serves the

**CITY OF FLAGSTAFF NORTH RFP**

The City's North Reservoir Filtration Plant is located at the base of Schultz Pass Road, in northwest Flagstaff. Photo: Erin Young, Fluid Solutions



## SCHULTZ FIRE

**DATES:** June 20th to June 30th, 2010 (100% contained)

**LOCATION:** Coconino National Forest northeast of Flagstaff

**BURN AREA:** 15,075 acres (23.5 square miles), 60% burned in first day

**TERRAIN:** Steep eastern slopes of San Francisco Peaks

**FUEL:** Ponderosa Pine and mixed conifer forests

**MONSOON:** 4th wettest on record with first rain on July 16th. Significant events followed on July 20th (1.78 in of

rain in 45 minutes) & August 16th (1.06 in of rain in 46 minutes)

**CAUSE:** Abandoned campfire at Schultz Tank and Elden Trail

**FATALITIES:** None due to the fire itself; a 12 year old girl was killed in a flash flood in her neighborhood on July 20th

**DAMAGE:** No structures were burned; a portion of the City of Flagstaff Inner Basin water pipeline traverses through burn area

**EVACUATIONS:** Over 1,000 residents from the Timberline and Doney Park area

Several days before containment of the Schultz Fire, the Forest Service Burned Area Emergency Response (BAER) team evaluated the burn area to identify potential resources at risk and to provide recommendations for mitigation measures. The BAER team divided the burn area into 11 basins based on burn severity, total area burned, and the steepness of the slopes, five of which were classified as high concern. The goal of the BAER program is to protect life, property, water quality, and deteriorated ecosystems from further damage.

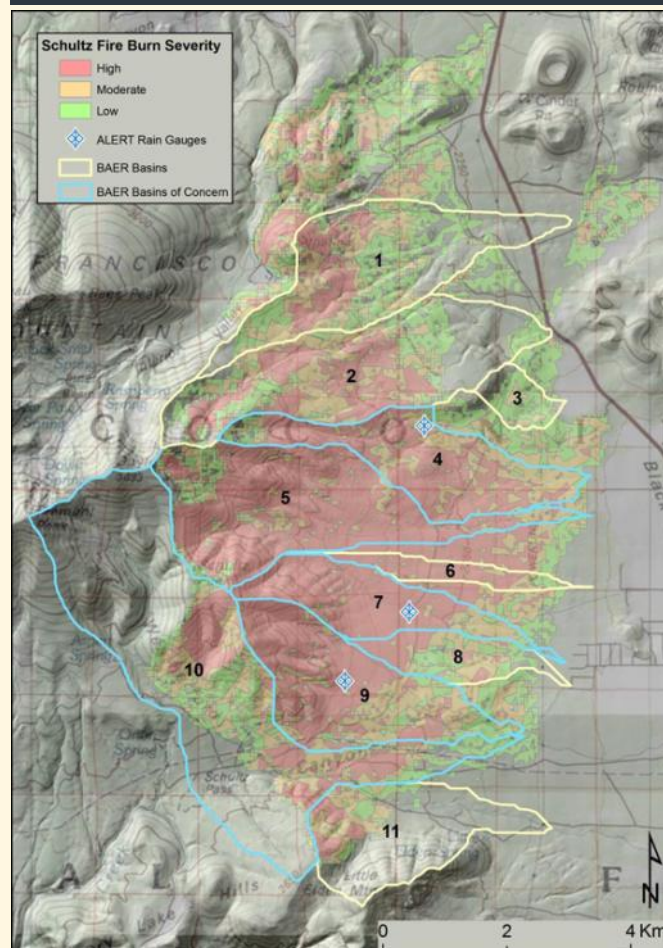
Mitigation goals identified were to reduce flooding potential and to retain onsite soils; specific attention was given the City of Flagstaff Waterline Road (FR 146) and cultural resources, soil erosion, and flooding impacts to those downstream.

Treatments recommended by the BAER were initiated by the Peaks Ranger District and completed by July 22nd. These included aerial application of certified weed-free straw mulch on lower slopes (5-60%) of high severity burns, adding manufactured wood straw on high severity burn slopes (40-100%), removal of 30 culverts along Schultz Pass Road (FR420) to facilitate flood passage, and placement of rip-rap on targeted fill slopes along Waterline Road. Specific to Waterline Road was the building of eight structures out of geotextile fabric and 12-inch-plus rock to protect vulnerable parts of the road. Additional treatments were made following the July 20th rain event that included aerial seeding, application of straw mulch, removing log-debris jams, and construction of waterbars and drains on Forest roads. Snowpack may have helped to stabilize the mulch and seed as a mechanism to reduce erosion the following year.

While the BAER treatments are part of an emergency stabilization effort, in the case of the Schultz Fire, the debris flows and high energy flood flows originating in the steep, burned slopes washed away what was estimated to be half of the straw mulch applied to the steep slopes. The treatments on low to moderate slopes have had very little impact on flooding and sediment movement. Additionally, all eight structures built to improve crossings along Waterline Road were washed out in the July 20th event. *Arizona Geological Survey, 2010*

## BURN SEVERITY

The map below shows the extent of the basins identified based on burn severity, total area burned, and slope gradient. *Coconino National Forest*





# Pipeline Reconstruction Project



In the aftermath of the 2010 Schultz Fire, monsoon storms triggered major debris flows on the steep mountain slopes of the San Francisco Peaks, causing substantial damage to Forest Road 146

(Waterline Road) and the existing drinking water pipeline. Although initial emergency repairs were made to the Waterline Road in the immediate aftermath of the wildfire, these repairs were washed out following the summer monsoon events. Waterline Road was damaged or rendered impassable in at least 28 locations. The pipeline was exposed in 17 locations and severed in one. Part of the damage to the pipeline was within the Kachina Peaks Wilderness Area and had to be relocated.

## Declaration of Emergency

On July 21, 2010 the Arizona's Governor Brewer declared a State of Emergency for the Schultz Fire Post-Fire Flood Emergency and requested federal assistance. On October 4, 2010 President Obama issued a major disaster declaration for the state of Arizona that opened up Federal and State funds through the Federal Emergency Management Agency (FEMA) and Arizona Department of Emergency Management (ADEM) to help repair the disaster area and mitigate future concerns. This project was considered eligible for federal funds under FEMA-1940-DR and was managed by ADEM. Funding for the reconstruction project was provided by FEMA, ADEM and City of Flagstaff. Funding for the relocation project was provided by the U.S. Department of Agriculture, U.S. Forest Service, Coconino National Forest, FEMA, ADEM and City of Flagstaff.

## Inner Basin Pipeline Repair Project Team

The pipeline starts within the Inner Basin of the San Francisco Peaks and extends for 13 miles downhill and terminates near the Museum of Northern Arizona at the City of Flagstaff North Reservoir Filtration Plant. Damages to the pipeline following the Schultz Fire extends along a 6 mile stretch of the pipeline, from approximately mile 2 to mile 8 along the alignment, as well as a section that occurs within the Kachina Peaks Wilderness Area. The City of

Flagstaff contracted with Hunter Contracting Co., of Gilbert, Arizona, and Jacobs Engineering Inc., Phoenix, Arizona, for construction and design services, and with Shephard-Wesnitzer, Inc., of Flagstaff, for inspection services. This project is the result of a partnership between the City and the Arizona Game and Fish, U.S. Fish and Wildlife, U.S. Forest Service, Coconino National Forest, FEMA, ADEM and Transwestern Pipeline Company.

## Reconstruction & Relocation

The repair of Waterline Road and the pipeline from the Inner Basin was split into two projects: Reconstruction and Relocation. As stated previously, the relocation project involved re-routing a portion of the pipeline that was located within the Kachina Peaks Wilderness Area with a new pipeline located outside of that boundary (see opposite page). The reconstruction project involved the repair of the pipeline and drainage crossings where damage occurred to the pipeline along Waterline Road.

## Design Philosophy

Multiple philosophies were considered during the reconstruction design selection process to repair the washed out drainage crossings, such as building bridges and installing culverts. These concepts were not selected due to the potential for clogging with subsequent debris flows. The final design philosophy selected is to allow any water or debris to flow over the top of the road, thereby protecting the encased pipeline at each crossing with rock-filled gabion baskets and concrete-covered roadway. The partners on this project also worked together to determine the proper level of runoff protection for design, whether it be to withstand a 10, 25, 50 or 100-year storm event. The final roadway design for the drainage crossings is for a 50-year storm event. The determination of event magnitude for future storms is discussed in the "Future Monitoring" section on pages 37 and 38 of this book. Lastly, due to the remote location of the project, and constraints due to the narrow road and the narrow rock tunnel on Waterline Road, the project was designed to minimize importing materials. Effort was taken to utilize on-site materials where possible.

**Estimated Reconstruction Cost: \$3.9 Million  
(75% Federal, 15% State, 10% City of Flagstaff)**

# Pipeline Relocation Project

Concurrent with the reconstruction of the pipeline and Waterline Road was the re-routing of a section of the pipeline through designated Wilderness area. Approximately 300 linear feet of concrete pipe was destroyed following the July 20th monsoon event. This section of pipe is located within the Kachina Peaks Wilderness area at the lower end of the damaged pipeline. When this section of pipe was last reconstructed in the 1930s, workers followed the gradient of the mountain to cross Weatherford Canyon and left the roadway. This was prior to the Wilderness designation in the 1980s.

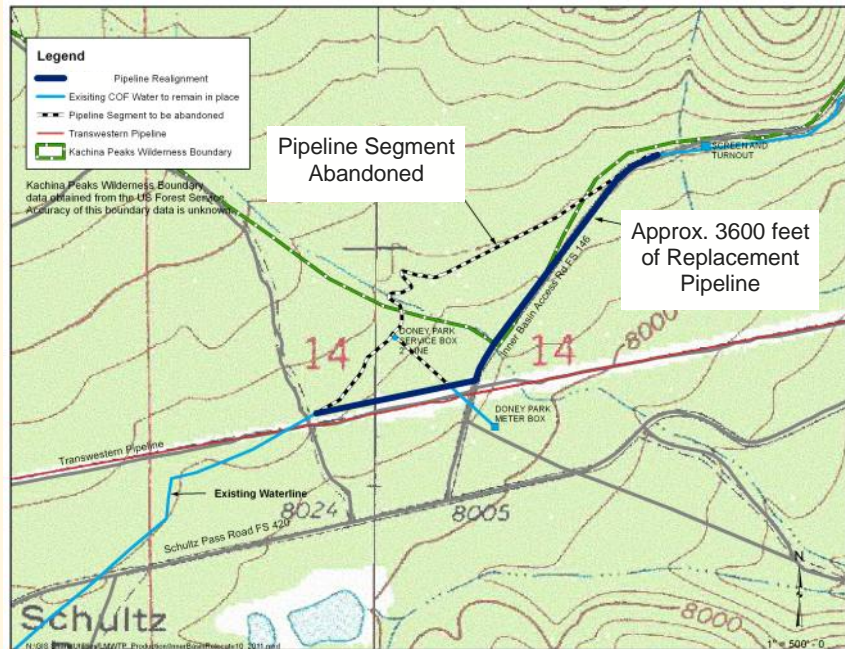
With work not possible through the Wilderness area, this project included the re-routing of approximately 3,600 linear feet of concrete pipe and replacing it with high-density polyethylene (HDPE). The new pipe was placed within the existing Forest Service roadway and Transwestern Pipeline easement within the forest. *Hunter/Jacobs, 2012.*

Funding for the relocation project was provided by the U.S. Department of Agriculture, U.S. Forest Service, Coconino National Forest, FEMA, ADEM and City of Flagstaff.

**Estimated Relocation Cost: \$600,000**

## PIPELINE RELOCATION

The map below shows the abandoned section of pipeline that was within the Kachina Peaks Wilderness Area, and the new location that follows Waterline Road and the Transwestern (gas) Pipeline. *Hunter/Jacobs, 2012*



## PIPELINE RELOCATION

The 15-inch concrete pipeline was relocated around Wilderness Area with 16-inch high density polyethylene (HDPE) pipe. Photos: Brad Hill, City of Flagstaff, Utilities Director



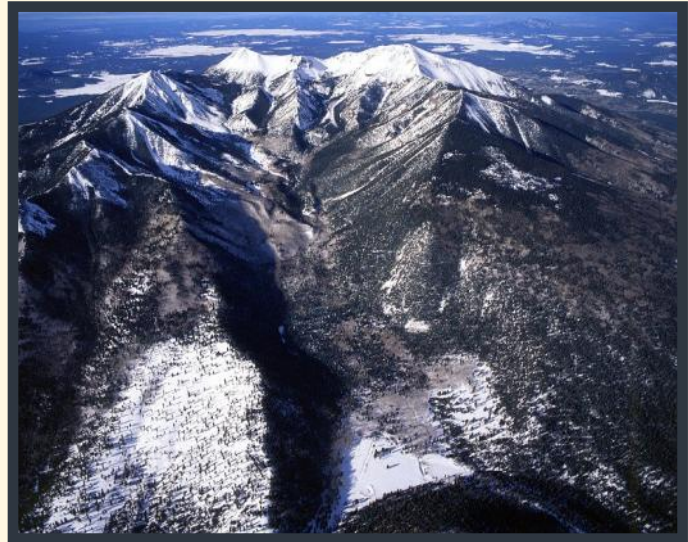
# The Peaks—Formation & Erosion

Flagstaff occurs within an area of northern Arizona with great topographic relief. A concern to the community is that of mass wasting and geologic disaster following wildfires, as is the case with the Schultz Fire. Below is a brief description of the geology, hydrology and geomorphology that comprise the San Francisco Peaks and Inner Basin.

## Geology

The peaks, Inner Basin, Dry Lake Hills, and Mount Elden are geologically young but extinct volcanoes of the San Francisco Volcanic Field. The area includes both Arizona's highest mountain—San Francisco Mountain, with Humphreys Peak rising to 12,633 feet—and the State's youngest volcano—Sunset Crater.

San Francisco Mountain is the only stratovolcano in the San Francisco Volcanic Field and was built by eruptions between about 1 and 0.4 million years ago by a magma of intermediate viscosity. Since then, much of the mountain has been removed to create the "Inner Basin." The missing material may have been removed quickly and explosively by an eruption similar to the 1980 eruption of Mount St. Helens, Washington. Elden Mountain, at the eastern outskirts of Flagstaff, is a dacite dome and consists of several overlapping lobes of lava. Sugarloaf Mountain, at the entrance to San Francisco Mountain's Inner Basin, is a rhyolite lava dome. Lava domes are formed by dacite and rhyolite magmas, which have high silica contents and are very viscous. *USGS Fact Sheet 017-01*



## AERIAL PHOTO OF PEAKS

Aerial photograph of the Inner Basin of the San Francisco Peaks. Humphreys Peak, in the rear of photo on right, is the highest peak in Arizona at 12,633 feet. Photo: Southwest Aerial Photography, Flagstaff

## Hydrology

The peaks are comprised of volcanic rock that is mostly covered by colluvial soils (loose and incoherent deposits ranging in size from clay to boulders) and alluvium (deposition of sediment by running water) above volcanic rock. The City of Flagstaff's Inner Basin water supply is derived from alluvial and glacial sediments within the Inner Basin that in places exceeds 500 feet in thickness. Alluvial sediments occur from about 10,500 feet at the head of the valley to 8,500 feet at Lockett Meadow. Evidence of three distinct glaciations have been found in the Inner Basin, the youngest evidence is that from the Wisconsin Glacial Episode some 65,000 to 15,000 years ago. Ice thickness may have been 1,000 feet during these glaciations. The alluvial and glacial sediments have yielded an average of 700 acre feet annually over the last sixty-plus years. The aquifer is estimated to store upwards of 1,200 acre-feet. *Inner Basin Aquifer Report, 1974; Inner Basin Yield Study, 1983; and 2012 City of Flagstaff Report to the Water Commission*

## Geomorphology

Not all sediment was entirely stable prior to the Schultz Fire as the freeze-thaw cycle allows for downslope movement of colluvial material and precipitation moves material to a degree. However, the post-fire debris flows responded to a number of major changes in the watershed:

- decreased canopy interception resulting in a greater percentage of rainfall available for runoff
- decreased amount of water normally lost as evapotranspiration resulting in increased baseflow or runoff in ephemeral streams
- lack of ground cover, litter, duff, debris resulting in increased runoff velocities and a decreased ability for interception and storage
- decreased infiltration due to the chemical and physical alteration of soil properties to a hydro-phobic state causing increased runoff.

*Arizona Geological Survey, 2010*



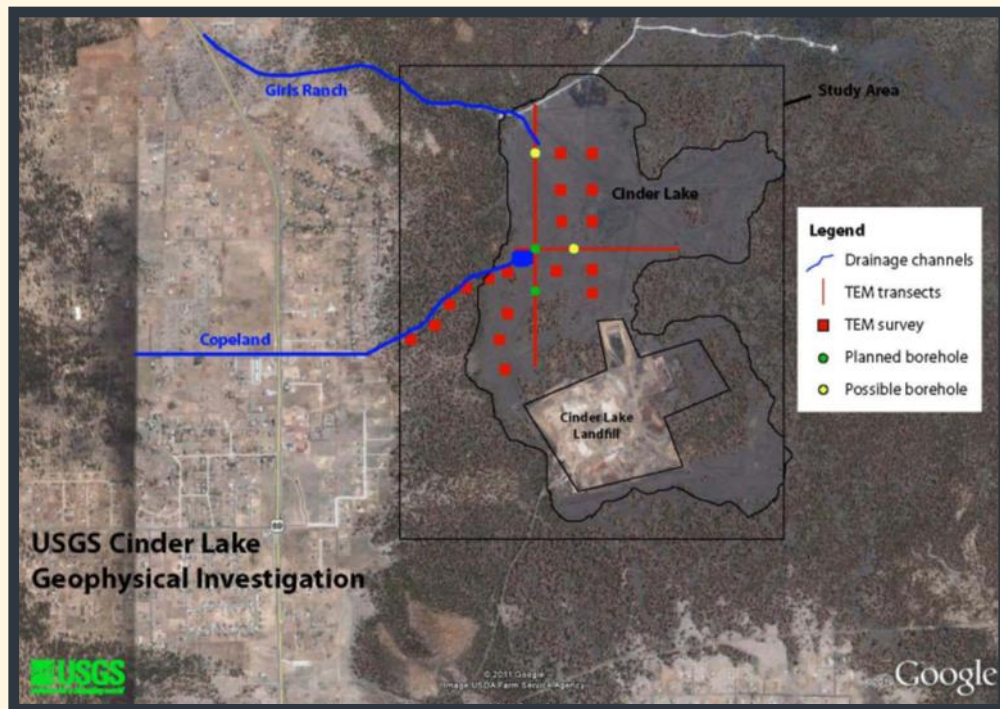
# Water Storage Capacity at Cinder Lake

The State of Arizona Incident Management Team led a group of agencies (Coconino County, Coconino National Forest Service, and the City of Flagstaff) in constructing a berm and channel that would temporarily convey stormwater runoff into a 400 acre (approximate) depression within the Cinder Lake Basin, located just north of the City of Flagstaff's Cinder Lake Landfill. At that time, the capacity of Cinder Lake to accept stormwater runoff was unknown. Therefore, in May, 2011 the County, US Geological Survey (USGS, led by Jamie Macy), and the City conducted two separate studies where nearly 41,800 linear feet of geophysical surveys were completed and 11 boreholes were drilled to determine the depth and hydrological characteristics of the unconsolidated surficial unit at Cinder Lake and to roughly characterize the hydrologic properties of the remaining volcanic package that lies beneath the surficial unit down to the boundary with the Kaibab Limestone. The City hired SDB, Inc., of Flagstaff, as a general contractor to perform project oversight and administration. SDB, Inc. subcontracted drilling to Boart Longyear, geophysical survey work to Zonge Engineering, and subsurface hydrologic characterization of the volcanic package to HydroSystems, Inc. The total cost of the project to the City Solid Waste enterprise fund was \$218,600.

Results from both studies suggest the interbedded cinders and alluvial deposits are about 30 feet thick and overlay basalt. The USGS calculated porosity for these deposits at 43 percent, which yields a total potential subsurface storage of Cinder Lake of about 4,000 acre-feet. Of concern, however, is how the water moves in the subsurface, whether vertically to the regional C-Aquifer, laterally due to a possible perched aquifer system to the Rio de Flag or towards the City of Flagstaff's unlined landfill south-southeast of Cinder Lake. *USGS-OFR 2012-1018*

While subsurface work was being conducted in May, 2011 the Forest Service requested proposals from the City for additional flood mitigation projects within Forest Service

boundaries. The project was guided by the Forest Service under the Burn Area Emergency Response (BAER) program. It was imperative that the contractor complete the project before the 2011 monsoon season got into full-swing. The City hired Turner Engineering to provide the conceptual designs of two earthen berms approximately 6 feet above grade, 27 feet wide, and a combined length of approximately 5,300 feet. SDB, Inc. and its subcontractor, Haydon Building Corp., used the conceptual plans to construct the two berms northwest of the landfill (within Forest Service boundaries). Compaction testing of the soil was conducted by Speedie and Associates. SDB, Inc. and its subcontractors ended up constructing the berms with soil from areas within the Cinder Lake Landfill. Overall 64,000 cubic yards of soil were excavated, processed, and placed in 26 days. The final cost of the project to the City Solid Waste enterprise



## LOCATION OF CINDER LAKE AND LANDFILL

Map showing location of USGS Cinder Lake geophysical investigation.



# Sites & Design

Documenting the condition of the pipeline and Waterline Road following the Schultz Fire began with an assessment by the Utilities Division as to the post-fire condition of the pipeline and access road prior to the onset of the monsoon. These early photos show an ash covered road and landscape that document the damage to vegetation and wildlife while the road was relatively unscathed (see Sites 14 & 24). Following monsoon storms, the City and numerous government agencies toured the damage and numbers were assigned to the damaged sites, starting at the Inner Basin and ending at Schultz Pass Road (see map at right). A couple of photos provided in this book were taken after the fire but before any rain. Most photos were taken following the first large monsoon event that occurred on July 20, 2010, after monsoon activity in September, 2010, and then upon completion of site construction in September, 2012.

Included with the site photos on the subsequent pages are map view and cross-section design drawings for the sites listed in the table below. The descriptions associated with the site information are also from the design report, including damage and drainage assessment notes from site visits and drainage event information that was evaluated in mid-September, 2010. This information is summarized in the table below for all sites.

The drainage event design for each site is the flow in cubic feet per second (cfs) that Hunter/Jacobs estimated based on drainage profiles and volume calculations in cubic yards (cu yds), for 10, 25, and 50 year events, in cubic feet per second. Any discussion of the pipeline condition is generally in reference to the 16-inch ductile iron pipeline (DIP) unless otherwise stated.

Reference to “Major” and “Minor” drainage crossings were based on whether upstream efforts were required to raise the channel grade preceding the access roadway surface, or if only a downstream repair was necessary. In the table at right, the Upstream/Downstream Crossing Repair is a “Major” repair while the Minor Drainage Crossing Repair did not require significant upstream mitigation efforts. Ford Crossings are at-grade crossing structures. Timber retaining walls are discussed on page 27 of this book. *Hunter/Jacobs, 2012*

**SITE SUMMARY TABLE** Summary of information from March, 2012 Hunter/Jacobs Design Report and final design for all sites.

Site Number	Photos and Design Drawings Provided In Booklet	Very Severe	Severe	Moderate	Minor	Erosion at Major Valley Location	Debris Over Road	Upslope Bank Sloughing	Loss of Cover Material	Loss of Timber Wall	Severed (linear feet severed)	Exposed (linear feet exposed)	No Damage or Exposure	Debris Flow	Concentrated Flows	Sheet Flow	Estimate of Material Lost September, 2010 (cubic yards)	Erosion to Bedrock	Gradient Equilibrium Reached	Upstream/Downstream Crossing Repair	Minor Drainage Crossing Repair	Ford Crossing	Timber Retaining Wall and How Many add ABC Aggregate	Mitigation Design
1					x	x	x					x	x		x		1,400					4	x	
2	x	x				x		x			40	19	x				1,850	x	x	x				
3				x				x				1	x	x	x		22					1		
4	x			x	x		x				10	x					30	x		x				
5	x		x			x	x	x			70		x				170	x		x				
6				x		x						x	x				30					x		
7	x		x			x		x			30	x					2,555		x	x				
8				x		x						x	x										x	
9	x		x			x		x			30	x		x			335	x		x				
10				x		x		x				x					70					x		
11	x			x		x		x			20		x				325			x				
12				x		x						x					6							x
13					x							x	x				30							x
14	x		x			x		x			40	x					1,800	x	x	x				
15	x		x			x		x			40		x	x			740	x	x	x				
16	x		x			x					40		x				1,560	x		x				
17				x								x	x				37	x				1	x	
18	x			x		x	x					x	x		x		332	x		x				
19				x		x			x			x		x			605					1		
20	x	x				x					40		x				2,500	x	x	x		1		
21				x		x						x	x	x			2,222					2	x	
22	x	x				x					50		x				3,700	x	x	x		1		
23				x										x			280					1		
24	x		x			x			x		30		x				1,850		x	x				
25	x			x		x						x	x				740			x				
26	x			x		x	x					x	x				925			x				
27					x		x				4		x	x			195				x			
28					x		x	x				x	x										x	

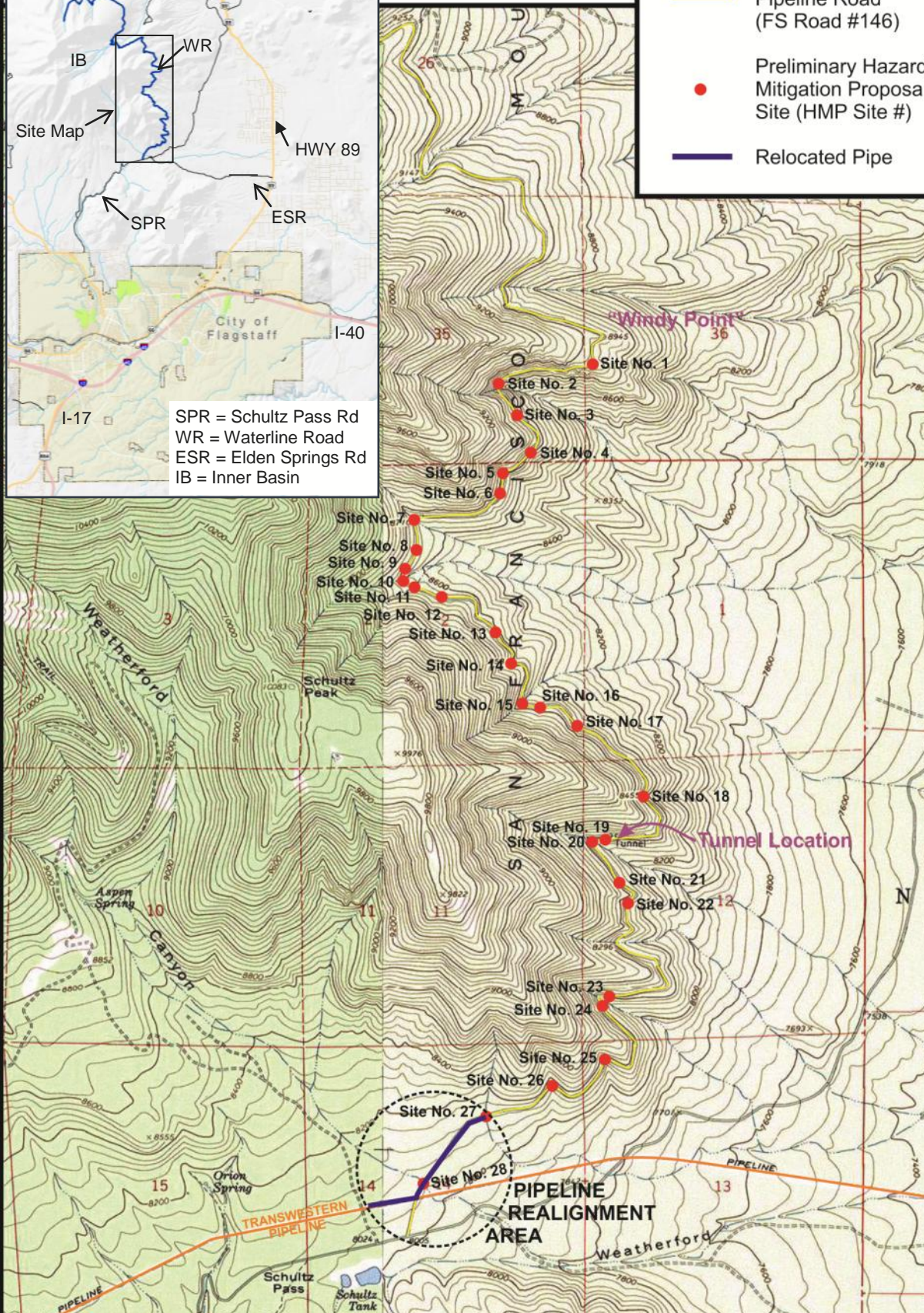
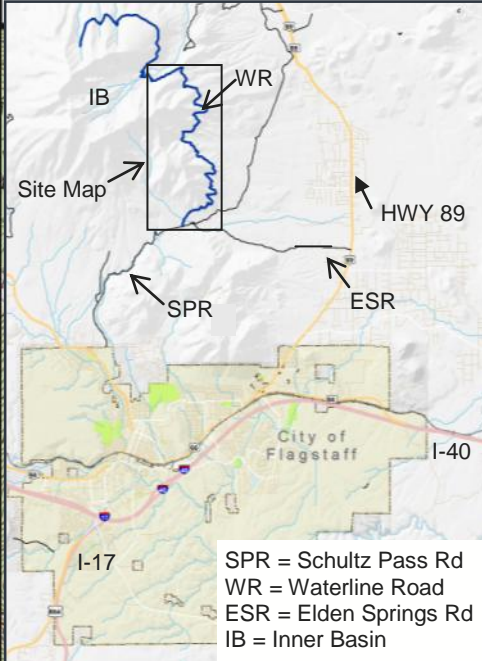


# City of Flagstaff - Utilities Division Schultz Flood Inner basin Pipeline Reconstruction Project

## LEGEND:



- Pipeline Road (FS Road #146)
- Preliminary Hazard Mitigation Proposal Site (HMP Site #)
- Relocated Pipe



**Hunter**  
CONTRACTING CO.

In Association With  
**JACOBS**



**Project Location Map**



## Site 2

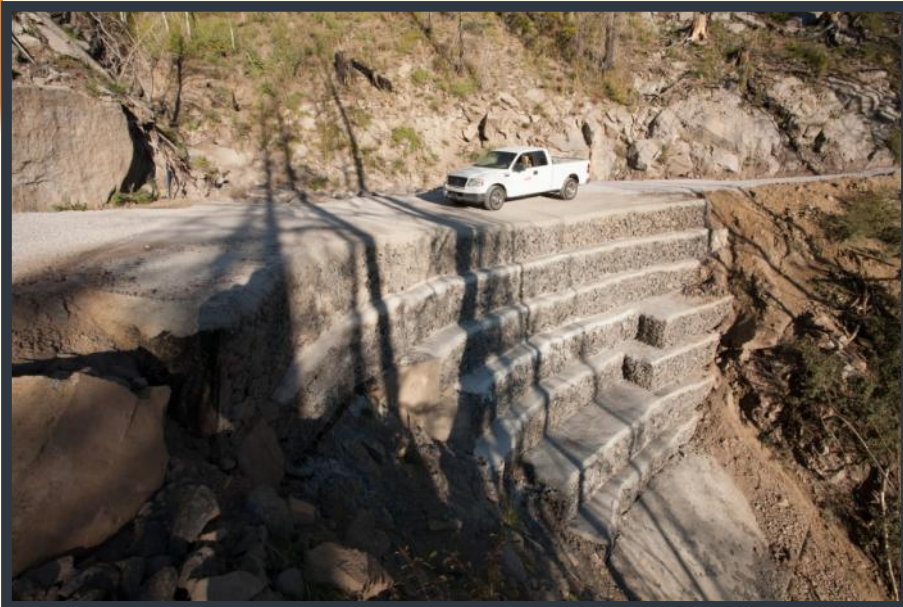


### SITE 2 DAMAGE ASSESSMENT

**Damage Assessment:** Very Severe  
**Nature of Damage:** Erosion at a natural inside drainage at a major valley or ravine  
**Pipe Condition:** 40 feet of 16-inch DIP lost and missing, another 19 feet exposed  
**Lost Material:** About 1,850 cu yds  
**Mass Wasting Character:** Flowing rock and larger trees and vegetation  
**Hunter/Jacobs Mitigation Design:** Upstream/Downstream Crossing Repair

### SITE 2 AFTER FIRST MAJOR MONSOON EVENT

Heavy erosion at drainage crossing including severed 16-inch DIP (left), and erosion to bedrock up-gradient (below), August 4, 2010. Photo: City of Flagstaff, Utilities Division



### SITE 2 FINAL CONSTRUCTION

(Above) Gabion structure, September 27, 2012.  
 (Right) Completed road crossing, September 27, 2012.  
 Photos: Tom Alexander Photography

### DRAINAGE EVENT DESIGN

$D_{10} = 289$  cfs

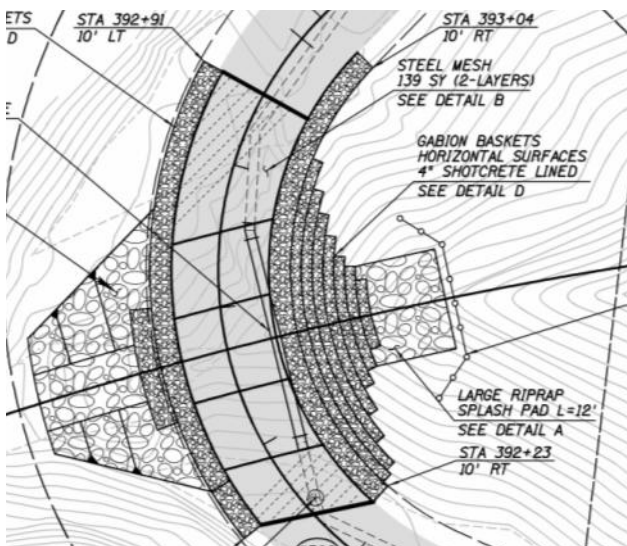
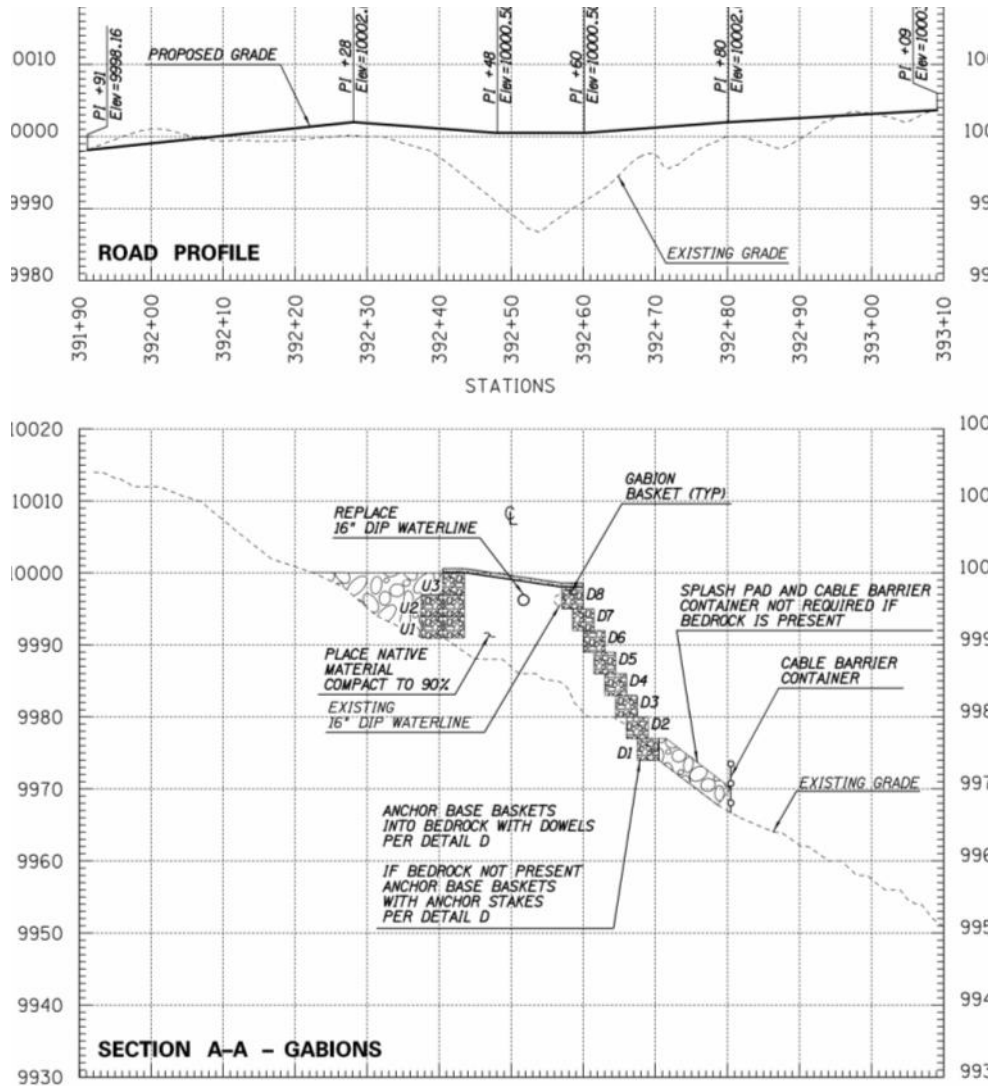
$D_{25} = 376$  cfs

$D_{50} = 447$  cfs





# Site 2



## SITE 2 DRAINAGE ASSESSMENT

Site 2 is located in the bend of the road at a major valley or ravine location. Stormwater runoff has traditionally passed over the access road and continued downstream in the ravine. With the event of the Schultz Fire, runoff rates have nearly doubled and upstream debris both in the form of flowing rock as well as large trees and uprooted vegetation are flowing down the valley. The flowline has reached equilibrium grade as much of the ravine has been lowered to the bedrock elevation, nearly 25 feet lower than the pre-fire drainageway profile. Loss of cover material up slope and down slope resulted in the exposure of bedrock.



## Site 4

4



### SITE 4 AFTER FIRST MAJOR MONSOON EVENT

View looking at drainage crossing and exposed 16-inch DIP on August 4, 2010. City of Flagstaff, Utilities Division



### SITE 4 FINAL CONSTRUCTION

Completed road crossing (above), and view looking up-gradient (right), September 27, 2012. Photo: Tom Alexander Photography



## 4





## Site 5

5



### SITE 5 POST-MONSOON

View looking at drainage crossing and exposed and suspended 16-inch DIP, September 9, 2010. Note the damaged geotextile fabric installed by the BAER team. Photo: FEMA



### SITE 5 FINAL CONSTRUCTION

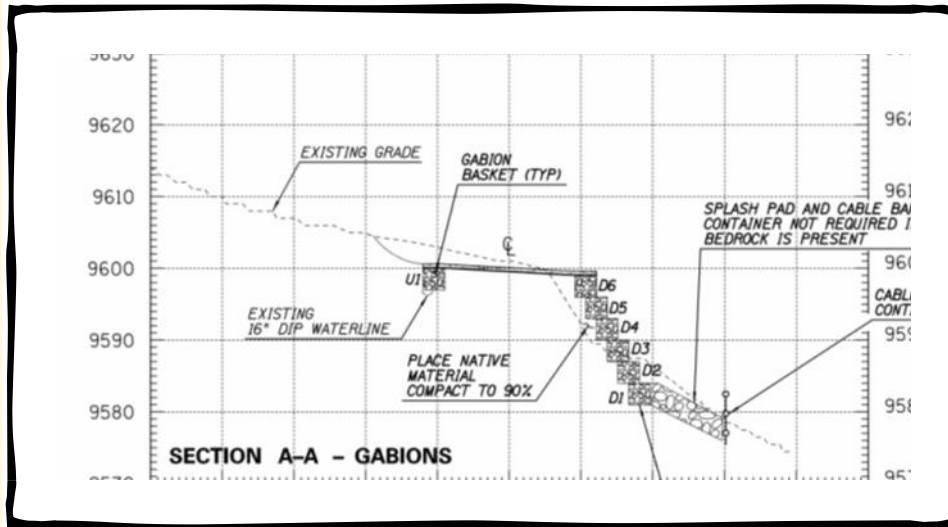
Completed road crossing (above), view looking down-gradient (left) and up-gradient (right), September 27, 2012. Photo: Tom Alexander Photography





# Site 5

5



## SITE 5 DAMAGE ASSESSMENT

**Damage Assessment:** Severe

**Nature of Damage:** Erosion of a natural inside drainage area at a major valley location

**Pipe Condition:** 70 feet of 16-inch DIP exposed and still in place

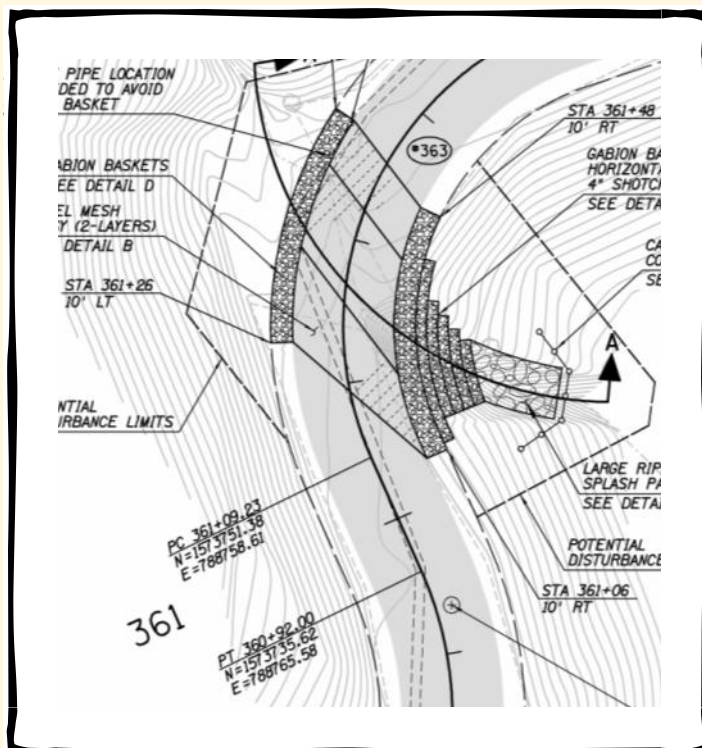
**Lost Material:** About 170 cu yds

**Mass Wasting Character:** Flowing rock and larger trees and vegetation; minimal loss of cover material upslope and severe loss of cover down slope to bedrock.

**Hunter/Jacobs Mitigation Design:** Minor Drainage Crossing Repair

## SITE 5 DRAINAGE ASSESSMENT

Site 5 is located in the bend of the road at a major valley location. Stormwater runoff has traditionally gone over the access road and downstream following the ravine. With the event of the Schultz Fire, runoff rates have nearly doubled, and upstream debris in the form of displaced soil and flowing rock has been deposited on the roadway. On the outside edge of the access road, the embankment and sideslopes have experienced significant erosion and rutting. Upstream, the runoff had eroded to bedrock. Downstream, runoff continues to erode the downstream soils to a point of equilibrium that has yet to be achieved.



## DRAINAGE EVENT DESIGN

$D_{10} = 32$  cfs

$D_{25} = 41$  cfs

$D_{50} = 48$  cfs



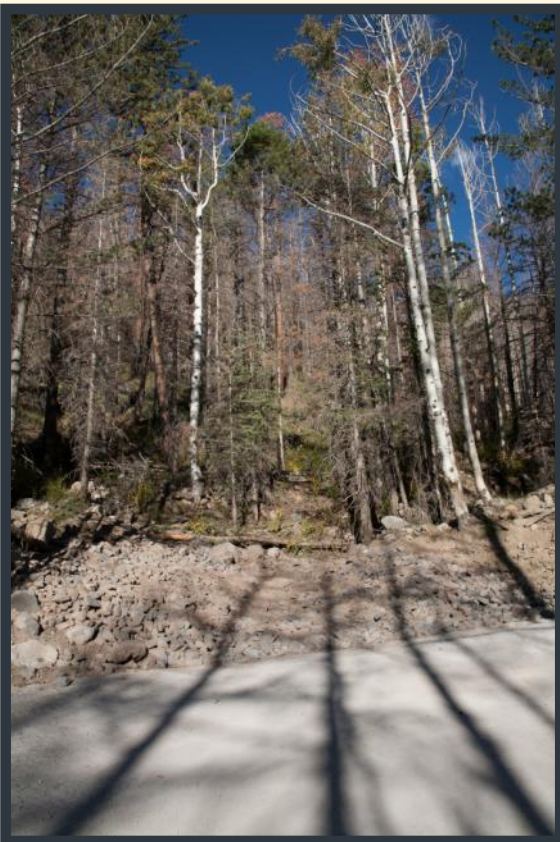
# Site 7

7



## SITE 7 AFTER FIRST MAJOR MONSOON EVENT

View of drainage crossing and exposed 16-inch DIP, August 4, 2010. Photo: City of Flagstaff, Utilities Division



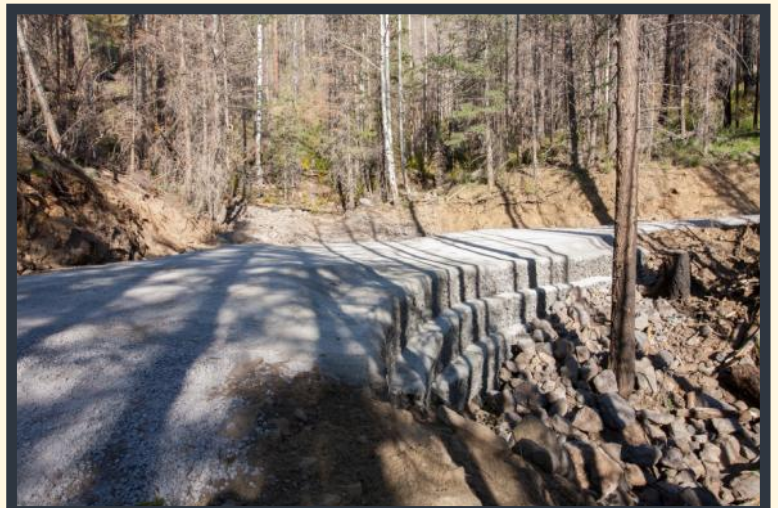
## SITE 7 FINAL CONSTRUCTION

View looking up-drainage from completed road crossing (above), and view looking at road crossing and gabion structure (right), September 27, 2012. Photos: Tom Alexander Photography



## SITE 7 POST-MONSOON

View looking down-gradient from road crossing, September 9, 2010. Photo: FEMA



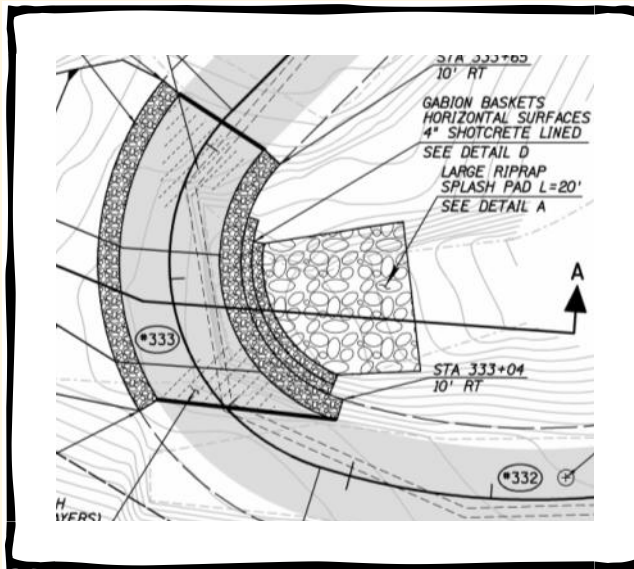






# Site 9

9



## SITE 9 DAMAGE ASSESSMENT

**Damage Assessment:** Severe

**Nature of Damage:** Upslope debris flow at major valley location

**Pipe Condition:** 16-inch DIP exposed but partially embedded for about 30 feet

**Lost Material:** About 335 cu yds

**Mass Wasting Character:** Flowing rock and larger trees and vegetation

**Hunter/Jacobs Mitigation Design:** Minor Drainage Crossing Repair



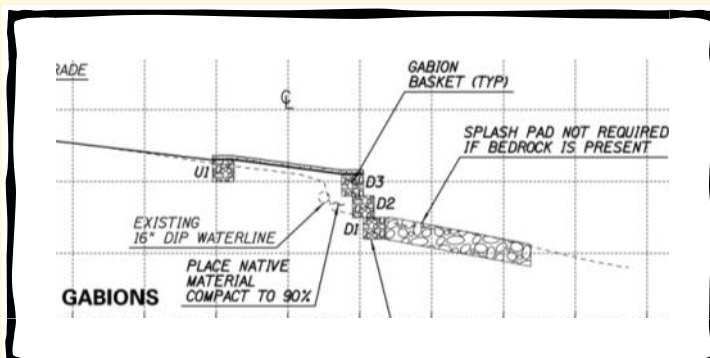
## SITE 9 AFTER FIRST MONSOON EVENT

Drainage crossing and exposed 16-inch DIP, August 4, 2010. Photo: City of Flagstaff, Utilities Division



## SITE 9 FINAL CONSTRUCTION

Road crossing and gabion structure, September 6, 2012. Photo: Erin Young, Fluid Solutions



## SITE 9 DRAINAGE ASSESSMENT

Similar in geometry and the impacts, due to erosion, as Site 7, Site 9 is located in the bend of the road at a major valley location. The pipeline itself is acting as a grade control structure that is preventing further upstream erosion, but has resulted in significant downstream erosion. Downstream, runoff continues to erode the downstream soils to find a point of equilibrium that has yet to be achieved. On the outside edge of the access road, the embankment and sideslopes have experienced significant erosion and rutting.

## DRAINAGE EVENT DESIGN

$D_{10} = 520$  cfs

$D_{25} = 691$  cfs

$D_{50} = 825$  cfs



# Site 11

## SITE 11 DAMAGE ASSESSMENT

**Damage Assessment:** Moderate

**Nature of Damage:** Debris and loss of cover material at relatively flat drainage ravine

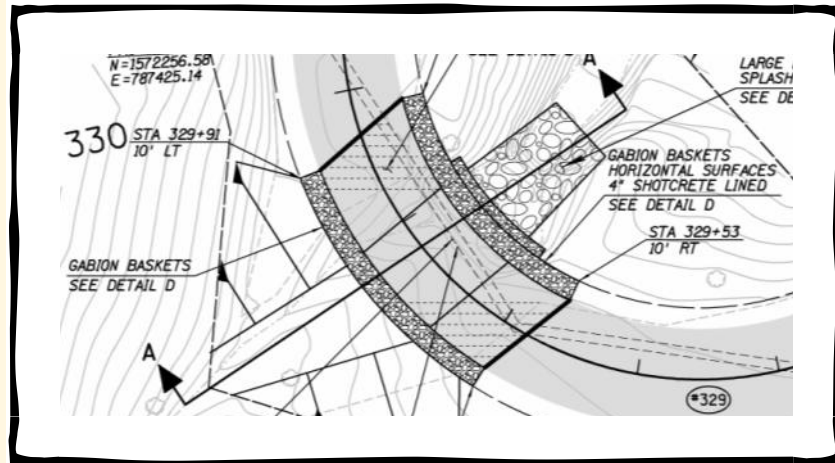
**Pipe Condition:** 20 feet of 16-inch DIP exposed and still in place

**Lost Material:** About 325 cu yds

**Mass Wasting Character:** Up-slope aggregate debris flow

**Hunter/Jacobs Mitigation Design:**

Minor Drainage Crossing Repair



11

## SITE 11 DRAINAGE ASSESSMENT

While this particular ravine is relatively flat compared to many of the drainageways being crossed, there is still enough erosion to expose the pipe and erode away some of the existing roadway section. While not as deep as some of the other repair sites, there is still downstream erosion that must be repaired and armored to prevent further damage to the pipe in the future. Upstream of the exposure site there is deposition of materials in the roadway that was removed.



## SITE 11 FINAL CONSTRUCTION

Completed road crossing, September 27, 2012. Photo: Tom Alexander Photography



## SITE 11 AFTER FIRST MONSOON EVENT

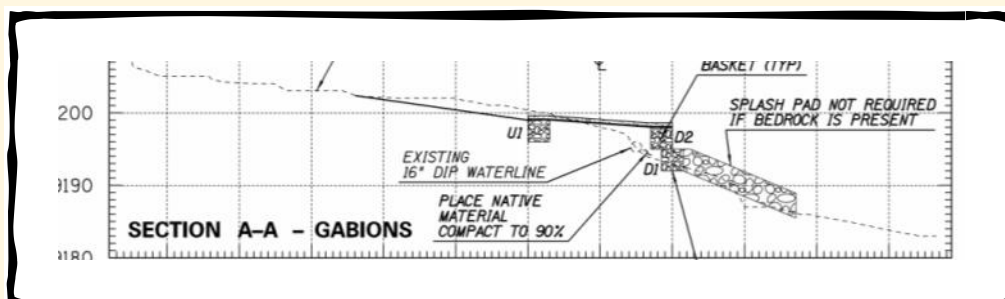
Drainage crossing and exposed 16-inch DIP, August 4, 2010. Photo: City of Flagstaff, Utilities Division

## DRAINAGE EVENT DESIGN

$D_{10} = 238$  cfs

$D_{25} = 324$  cfs

$D_{50} = 391$  cfs



20



# Site 14

## SITE 14 DAMAGE ASSESSMENT

**Damage Assessment:** Severe  
**Nature of Damage:** Erosion and loss of cover material at a natural inside drainage area at a major valley location

**Pipe Condition:** 40 feet of 16-inch DIP exposed and still in place

**Lost Material:** About 1,800 cu yds

**Mass Wasting Character:** Flowing rock and larger trees and vegetation

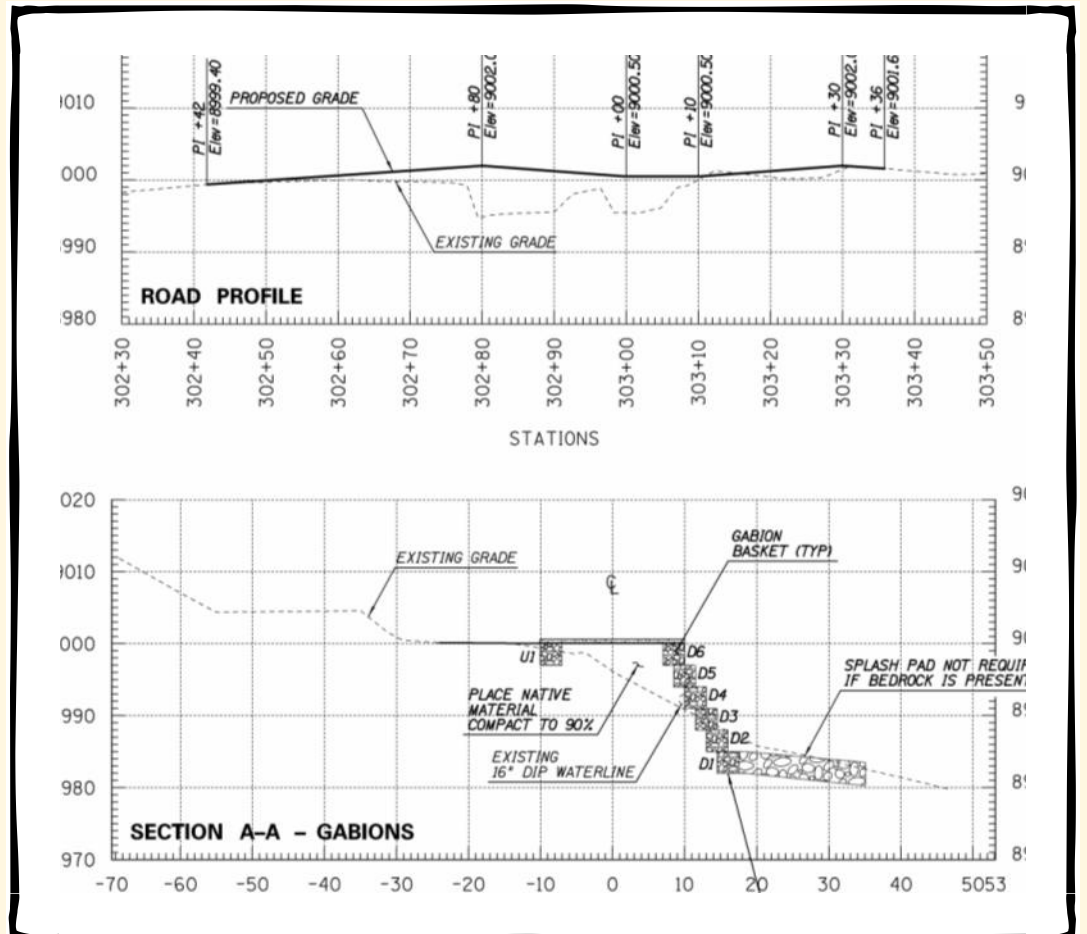
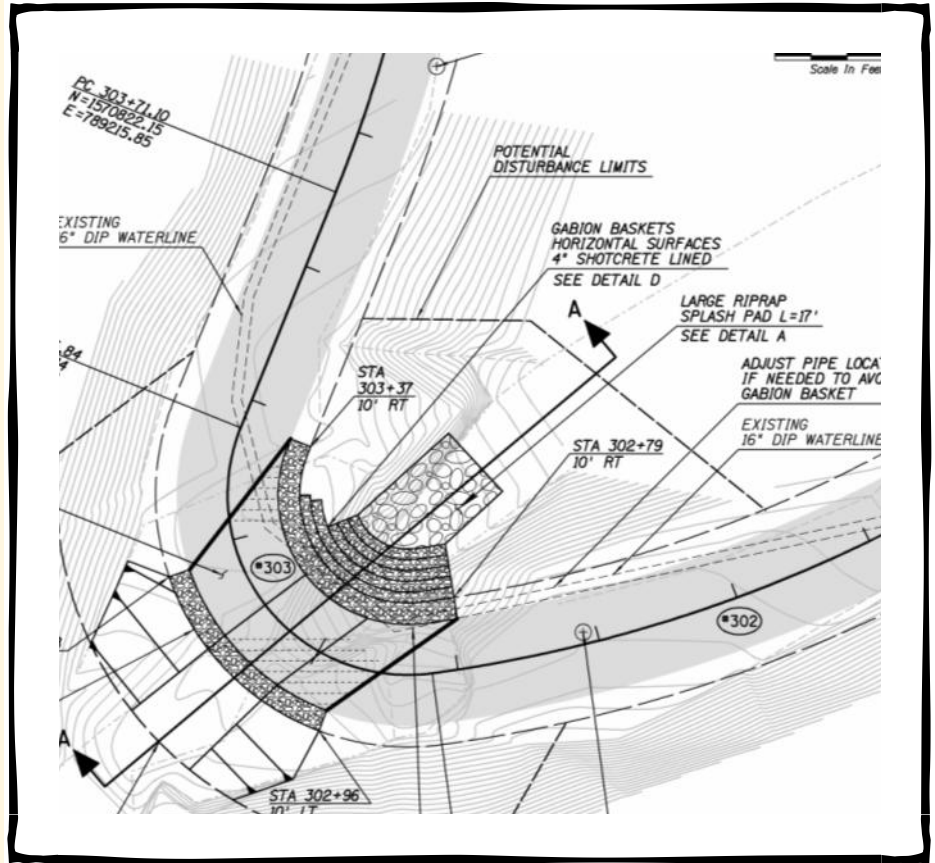
**Hunter/Jacobs Mitigation Design:** Upstream/Downstream Crossing Repair

## SITE 14 DRAINAGE ASSESSMENT

Similar in geometry with slightly more severe erosion conditions than Site 7, Site 14 is located in the bend of the road at a major valley location. The access road embankment has eroded away down to near bedrock, the embankment and sideslopes have experienced significant erosion and rutting. This site has minimal loss of cover upslope and more severe erosion to bedrock downslope. Upstream debris in the form of displaced soil and flowing rock are depositing at the upstream segment of this crossing. The pipeline itself for a period of time was acting as a grade control structure that was preventing further upstream erosion. The headcutting undermined the materials around the pipe and continued to erode upstream of the pipe itself, leaving the pipe exposed above existing ground.

## DRAINAGE EVENT DESIGN

$D_{10} = 163 \text{ cfs}$   
 $D_{25} = 210 \text{ cfs}$   
 $D_{50} = 246 \text{ cfs}$





# Site 14



## SITE 14 POST-FIRE & PRE-MONSOON (LEFT) & AFTER FIRST MAJOR MONSOON EVENT (RIGHT)

View looking at drainage crossing on July 7, 2010 prior to the onset of the monsoon season (left), and on August 4, 2010 after the first major monsoon event that occurred on July 20, 2010 (right). Notice the slight depression in the drainage (swale) with no defined channel bottom in the photo on the left and the debris and scour to bedrock in subsequent photos. Photos: Utilities Division, City of Flagstaff

14



## SITE 14 FINAL CONSTRUCTION

Completed road crossing and gabion structure, September 27, 2012. Photo: Tom Alexander Photography



## SITE 14 POST-MONSOON

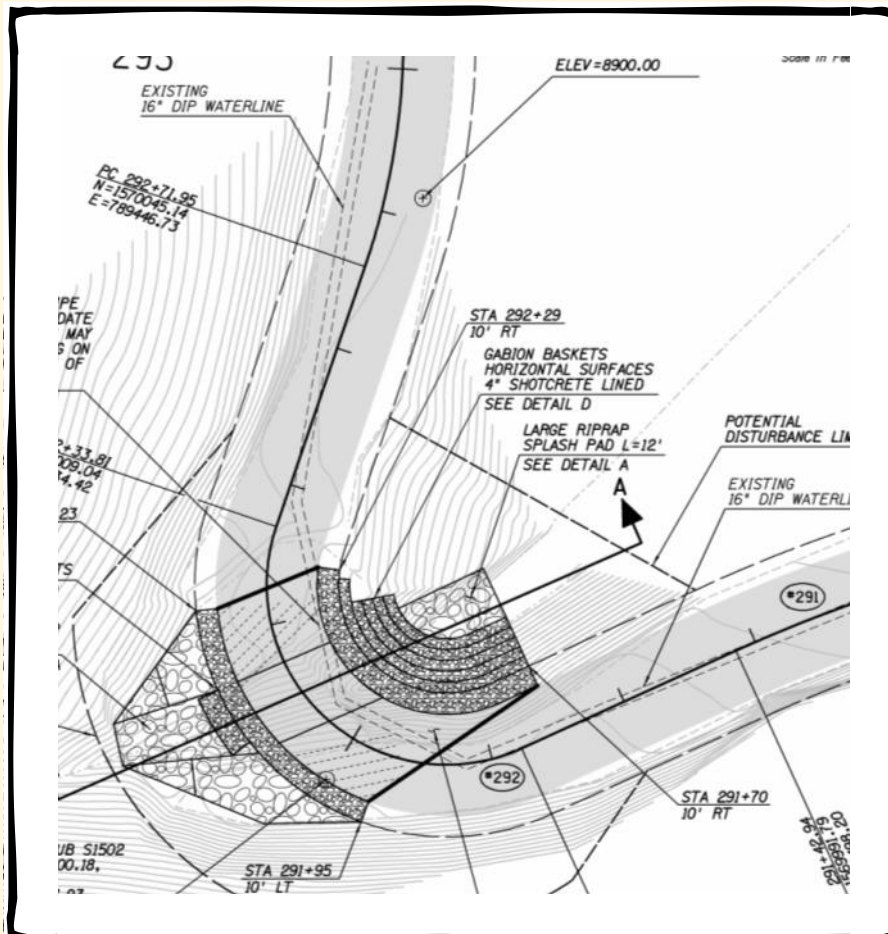
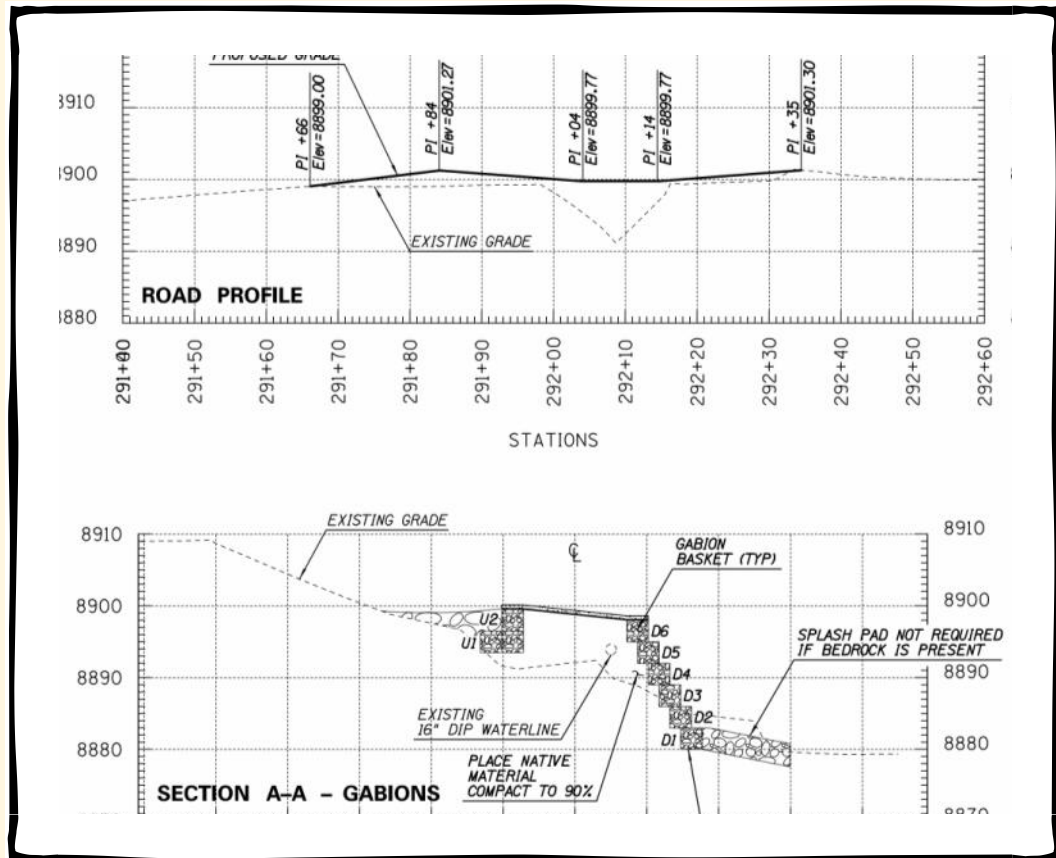
View looking at drainage crossing and exposed and suspended 16-inch DIP, September 9, 2010. Photo: FEMA

## BAER MITIGATION SITE

This location is one of the sites where the BAER team attempted to protect the roadway and pipeline with geotextile fabrics and large riprap immediately after the fire. With the monsoon rains, all of the materials were washed downstream and essentially pushed aside.



# Site 15



## SITE 15 DRAINAGE ASSESSMENT

Similar in geometry with and erosion to the conditions of the previous Site 14, Site 15 is located in the bend of the road at a major valley location. The pipeline itself for a period of time was apparently acting as a grade control structure that was preventing further upstream erosion. Ultimately, the headcutting undermined the materials around the pipe and continued to erode upstream of the pipe crossing itself, leaving the pipe exposed above the existing ground. The access road embankment has eroded away down to near bedrock and the embankment and sideslopes have experienced significant erosion and rutting. Runoff continues to erode downstream soils to find a point of equilibrium that has yet to be achieved, but is still very rocky in nature.



# Site 15



## SITE 15 AFTER FIRST MAJOR MONSOON EVENT

View looking at drainage crossing, exposed 16-inch DIP, and erosion to bedrock above, August 4, 2010. Photo: Utilities Division, City of Flagstaff

## SITE 15 DAMAGE ASSESSMENT

**Damage Assessment:** Severe

**Nature of Damage:** Erosion of a natural inside drainage area at major valley location

**Pipe Condition:** 40 feet of 16-inch DIP exposed and suspended but still in place

**Lost Material:** About 740 cu yds

**Mass Wasting Character:** Up-slope aggregate debris flow to bedrock

**Hunter/Jacobs Mitigation Design:** Upstream/Downstream Crossing Repair



## SITE 15 POST-MONSOON

View looking at drainage crossing and suspended 16-inch DIP, September 9, 2010. Photo: FEMA

## SITE 15 FINAL CONSTRUCTION

Completed road crossing and gabion structure, September 27, 2012. Photo: Tom Alexander Photography

## DRAINAGE EVENT DESIGN

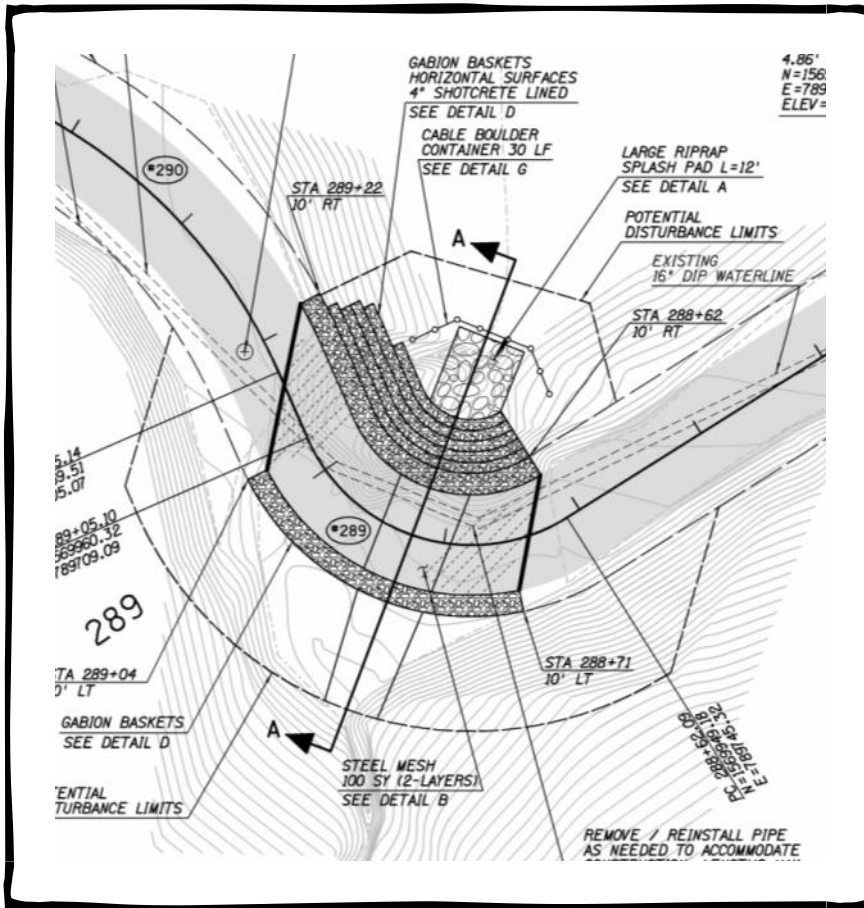
$D_{10} = 252$  cfs

$D_{25} = 324$  cfs

$D_{50} = 380$  cfs



# Site 16



## SITE 16 DAMAGE ASSESSMENT

**Damage Assessment:** Severe

**Nature of Damage:** Severe erosion at a natural inside drainage at a major valley location

**Pipe Condition:** 40 feet of 16-inch DIP exposed and partially embedded but still in place

**Lost Material:** About 1,560 cu yds

**Mass Wasting Character:** Granular debris flow material up-slope of DIP

**Hunter/Jacobs Mitigation Design:** Upstream/Downstream Crossing Repair

16

## SITE 16 DRAINAGE ASSESSMENT

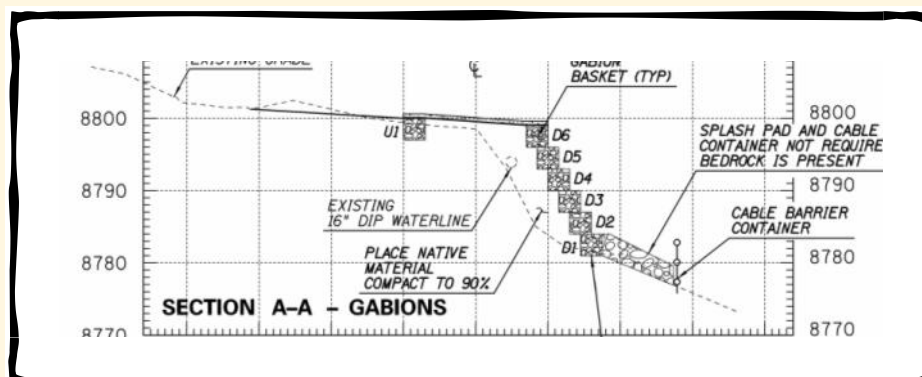
Similar in geometry with and erosion to the conditions of the previous Site 15, Site 16 is located in the bend of the road at a major valley location. On the down slope side of the DIP, there is a severe cut/drop that on Sept 9, 2010 measured approximately 30 feet deep and approximately 70 feet down slope and about 40 feet wide. Upstream debris in the form of displaced soil and flowing rock are depositing at the upstream segment of this crossing. Over time this drainageway has apparently gained elevation by depositing materials over the bedrock and raising the grade of the entire drainage ravine. The flows through the site are now resulting in heavy headcutting from the downstream erosion. The headcutting undermined the materials around the pipe, leaving the pipe exposed above the existing ground. The access road embankment and sideslopes have experienced significant erosion and rutting.

## DRAINAGE EVENT DESIGN

$D_{10} = 47$  cfs

$D_{25} = 61$  cfs

$D_{50} = 71$  cfs





# Site 16



## SITE 16 AFTER FIRST MAJOR MONSOON EVENT

View looking at drainage crossing and exposed 16-inch DIP on August 4, 2010. City of Flagstaff, Utilities Division



## SITE 16 POST-MONSOON

View looking at drainage crossing and exposed pipe, September 9, 2010. Photo: FEMA



## SITE 16 FINAL CONSTRUCTION

Completed road crossing (above), and view looking down-gradient (left), September 27, 2012. Photos: Tom Alexander Photography



# Timber Retaining Walls



## TIMBER WALL CONSTRUCTION

Timber construction as retaining structures, September 6, 2012. Photo: Erin Young, Fluid Solutions

## TIMBER RETAINING WALL STRUCTURES

There are 23 locations where timber retaining walls were built along Waterline Road. These locations were experiencing damage from flows that were eroding the edges of the roadway. Runoff was concentrating to a single discharge point and head-cutting through the roadway surface. At these locations a timber retaining structure was constructed such that the runoff will continue to use the same path through the site but the roadway will be protected from further erosion.

## TIMBER RETAINING WALL LOCATIONS

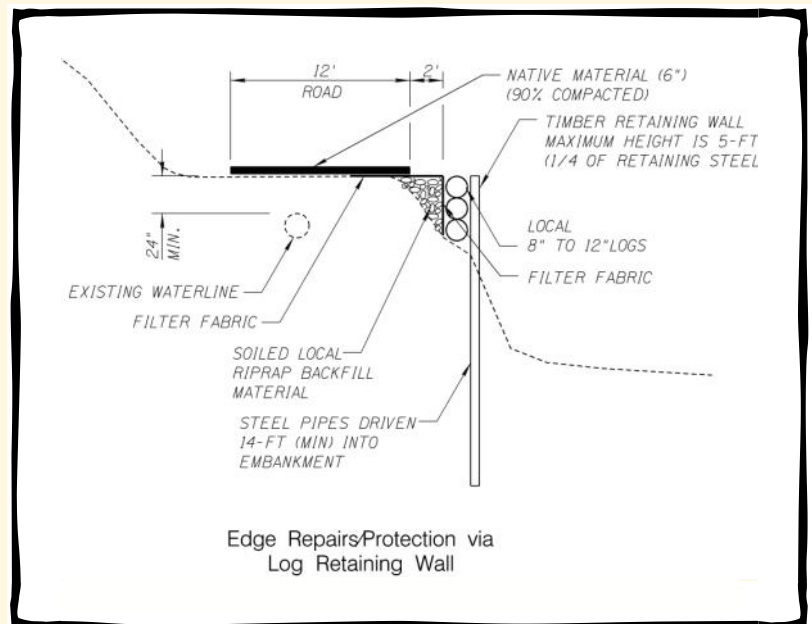
Timber retaining walls were built at the site locations listed in the table on page 9 but also at these stations that occur between sites: 176+50 (1), 179+75 (2), 232+25 (1), 233+50 (1), 239+75 (1), 239+40 (1), 239+00 (1), 244+00 (1), 258+10 (1), 279+20 (1), 370+00 (1)

Chuck Lumer, Construction Manager, Hunter Contracting Co.



## TIMBER WALL CONSTRUCTION

Timber retaining wall construction showing vertical steel pipe supports, September 27, 2012. Photo: Tom Alexander Photography



## DESIGN DRAWING

Log retaining wall design details. Jacobs Engineering Inc.



# Site 18

## SITE 18 DAMAGE ASSESSMENT

**Damage Assessment:** Moderate

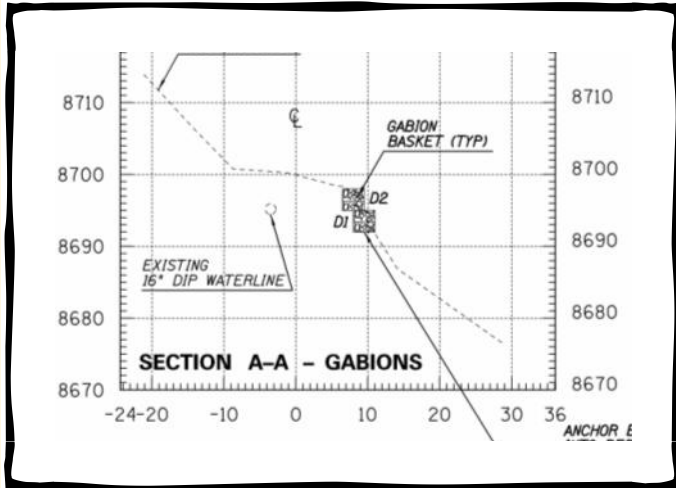
**Nature of Damage:** Sheetflow at moderate bend in road where minor depression upstream concentrates flows

**Pipe Condition:** No damage or exposure

**Lost Material:** About 332 cu yds, including damage down the road

**Mass Wasting Character:** Sheet flow, granular backfill and large rip rap type material. Erosion to bedrock downstream of crossing.

**Hunter/Jacobs Mitigation Design:** Minor Drainage Crossing Repair

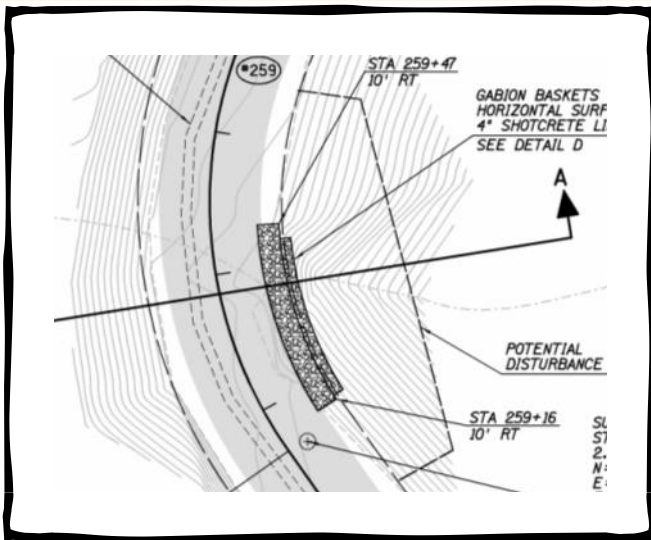


## SITE 18 DRAINAGE ASSESSMENT

Site 18 is located at a moderate bend in the access road where there is a minor depression in the upstream topography to concentrate the upstream flows to this location. The embankment and sideslopes are experiencing significant erosion resulting in the reduction of the access road and supporting embankment. The runoff continues to erode the downstream soils to find a point of equilibrium that has yet to be achieved, but left alone, will headcut through the access road and expose the pipeline.

### DRAINAGE EVENT DESIGN

$D_{10} = 18$  cfs  
 $D_{25} = 20$  cfs  
 $D_{50} = 24$  cfs



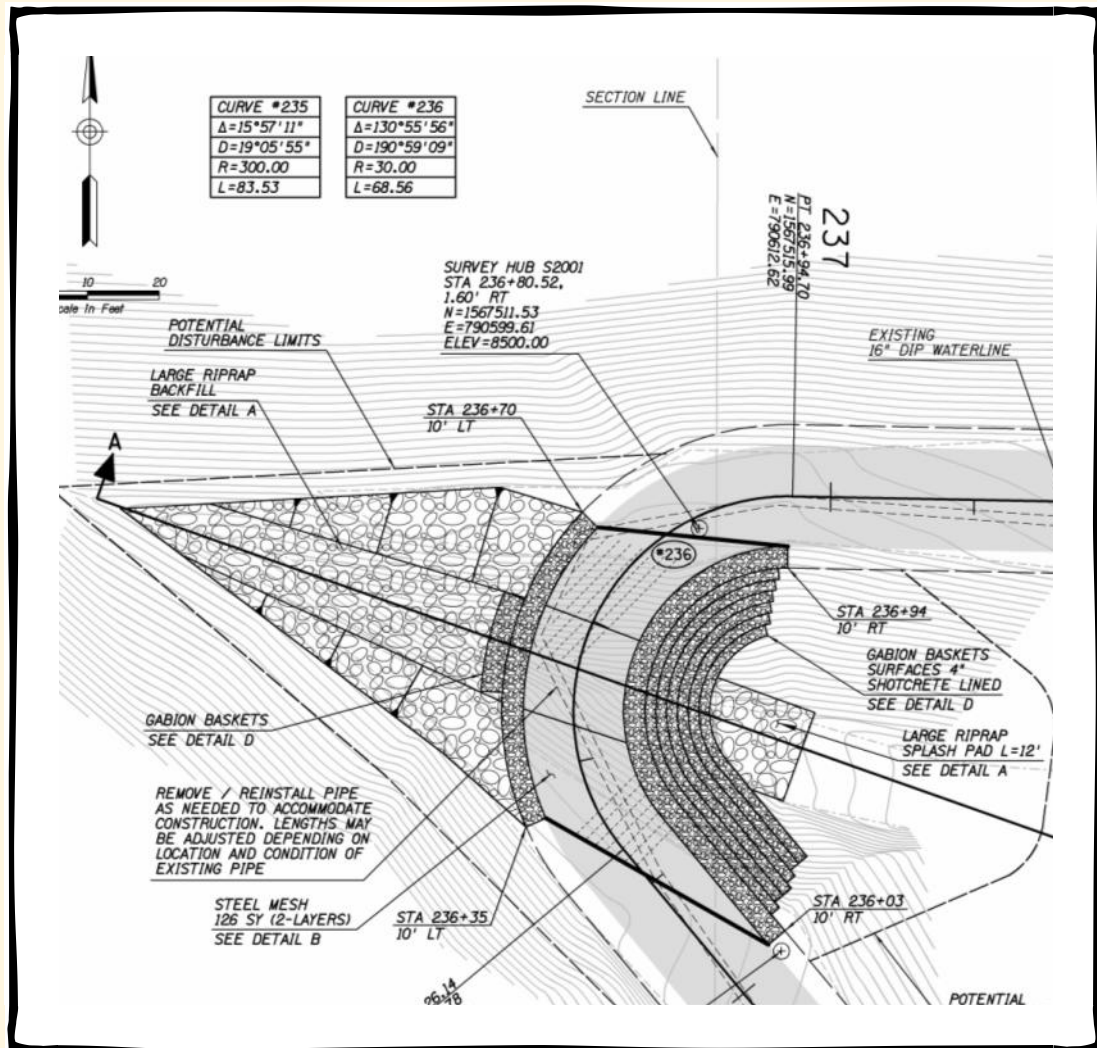
## SITE 18 POST-MONSOON & FINAL CONSTRUCTION

(Above) Damage to road and to outside edge of road, September 9, 2010. Photo: FEMA

(Left) Completed road crossing, September 27, 2012. Photo: Tom Alexander Photography



# Site 20



## SITE 20 DRAINAGE ASSESSMENT

At this location, 16-inch pipe was removed to rebuild the slope and regain the 24-inch minimum cover over the DIP. The flowline had reached an equilibrium grade as much of the ravine has been lowered to be either at or near the bedrock elevation, nearly 25 feet lower than the pre-fire drainageway profile.

## SITE 20 DAMAGE ASSESSMENT

**Damage Assessment:** Very severe

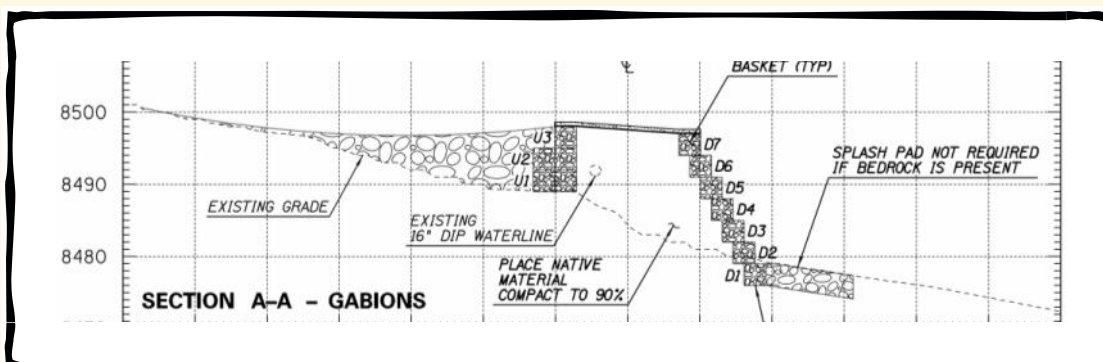
**Nature of Damage:** Erosion at a major valley or ravine at a natural inside drainage

**Pipe Condition:** 16-inch DIP was suspended in place

**Lost Material:** In excess of 2,500 cu yds; hard to estimate because it continued so far upslope

**Mass Wasting Character:** Flowing rock as well as large trees and uprooted vegetation, erosion to bedrock upslope and downslope

**Hunter/Jacobs Mitigation Design:** Upstream/Downstream Crossing Repair



## DRAINAGE EVENT DESIGN

D<sub>10</sub> = 508 cfs  
D<sub>25</sub> = 655 cfs  
D<sub>50</sub> = 770 cfs



## Site 20



### SITE 20 POST-MONSOON

Exposed 16-inch DIP at drainage crossing, September 9, 2010. Photo: FEMA



### SITE 20 FINAL CONSTRUCTION

(Above) View looking down gradient, September 27, 2012.

(Left) Completed road crossing, September 27, 2012.

Photos: Tom Alexander Photography



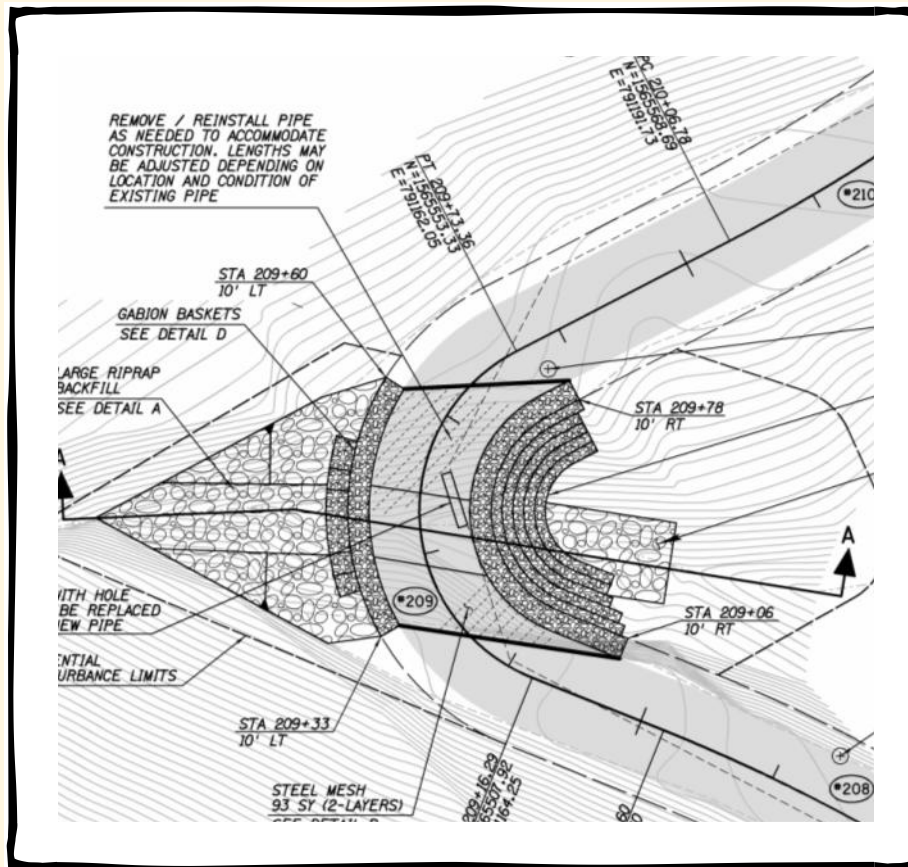
# Site 22

## SITE 22 DRAINAGE ASSESSMENT

This site has sustained very severe damage in terms of erosion. Stormwater runoff has traditionally gone over the access road and downstream following the ravine. With the event of the Schultz Fire, runoff values have nearly doubled, and upstream debris in the form of flowing rock as well as large trees and uprooted vegetation are "flowing" down the valley. The flowline has reached an equilibrium grade as much of the ravine has been lowered to be either at or near the bedrock elevation, nearly 20 feet lower than the pre-fire drainageway profile.

## DRAINAGE EVENT DESIGN

$D_{10} = 252$  cfs  
 $D_{25} = 325$  cfs  
 $D_{50} = 383$  cfs



## SITE 22 POST-MONSOON

Exposed 16-inch DIP at drainage crossing, September 9, 2010. Photo: FEMA



# Site 22



## SITE 22 AFTER FIRST MAJOR MONSOON EVENT

View looking at drainage crossing and suspended DIP on August 4, 2010. Photo: City of Flagstaff, Utilities Division

## SITE 22 DAMAGE ASSESSMENT

**Damage Assessment:** Very Severe

**Nature of Damage:** Erosion at a natural inside drainage at a major valley or ravine location

**Pipe Condition:** 50 feet of DIP exposed and suspended; one joint of DIP had a 3-inch hole in the top of the barrel

**Lost Material:** About 3,700 cu yds, however hard to estimate because it continued so far upslope

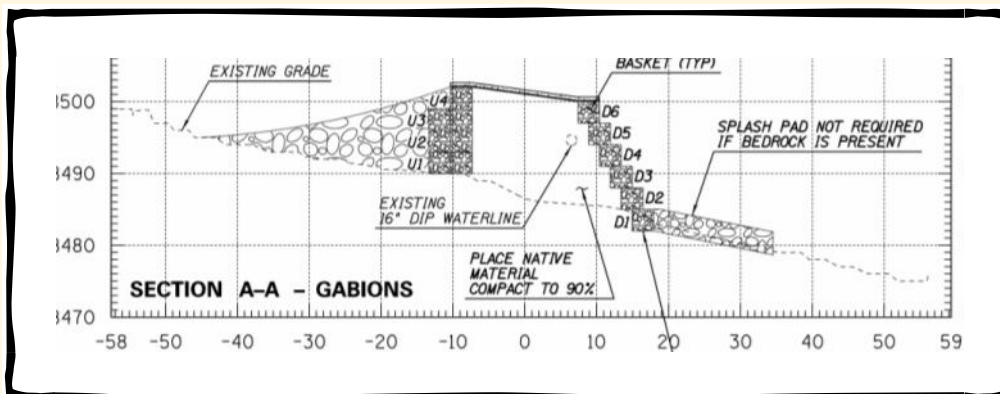
**Mass Wasting Character:** Erosion to bedrock up and down slope, flowing rock and large trees and uprooted vegetation

**Hunter/Jacobs Mitigation Design:** Upstream/Downstream Crossing Repair



## SITE 22 FINAL CONSTRUCTION (LEFT & BELOW)

Completed road crossing gabion structure and timber retaining wall, September 27, 2012. Photo: Tom Alexander Photography





# Site 24

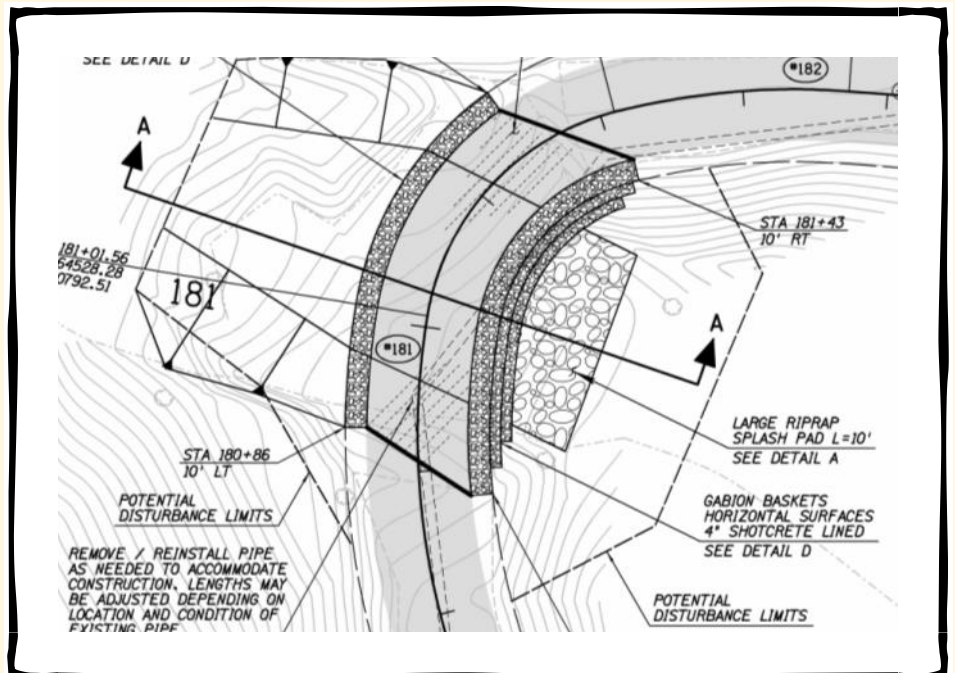


## SITE 14 POST-FIRE & PRE-MONSOON

View looking up drainage crossing on July 7, 2010, prior to the onset of the monsoon. Notice the slight depression (swale) of the drainage with no defined channel bottom in comparison with the photograph by FEMA on the adjacent page. The tree stump (in foreground of this photo) serves as a marker to compare the amount of debris that filled the drainage. Photo: Utilities Division, City of Flagstaff

## SITE 24 DAMAGE ASSESSMENT

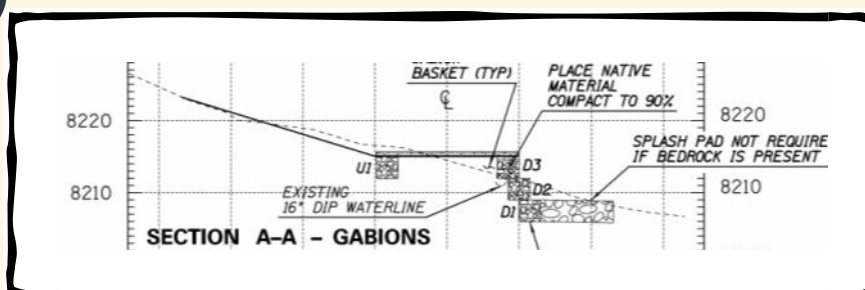
**Damage Assessment:** Severe  
**Nature of Damage:** Loss of cover material where bend occurs in road at major valley location  
**Pipe Condition:** 30-feet of 16-inch DIP exposed  
**Lost Material:** About 1,850 cu yds  
**Mass Wasting Character:** Displaced soil and flowing rock  
**Hunter/Jacobs Mitigation Design:** Minor Drainage Crossing Repair



## SITE 24 DRAINAGE ASSESSMENT

This is a 100-foot wide rocky channel with gentle gradients up and down slope (20% grade). The upslope was level with the top of the DIP, however, downslope of the DIP was an 8-foot cut that continued downslope for about 50 feet. The pipeline itself was acting as a grade control structure that was preventing further upstream erosion, but had resulted in downstream erosion. Upstream debris in the form of displaced soil and flowing rock has deposited upstream of the crossing. On the outside edge of the access road, the embankment and sideslopes have experienced significant erosion and rutting. Runoff continues to erode the downstream soils to find a point of equilibrium that has yet to be achieved, but is still very rocky in nature.

24



## DRAINAGE EVENT DESIGN

$D_{10} = 133 \text{ cfs}$   
 $D_{25} = 177 \text{ cfs}$   
 $D_{50} = 212 \text{ cfs}$



# Site 24



## SITE 24 AFTER FIRST MAJOR MONSOON EVENT

View looking at drainage crossing (left) and boulder on pipe (below), August 4, 2010. Photo: Utilities Division, City of Flagstaff



## SITE 24 POST-MONSOON

View looking at drainage crossing on September 9, 2010. Compare with photo on opposite page. Photo: FEMA



## SITE 24 FINAL CONSTRUCTION

View looking at completed drainage crossing on September 6, 2012. Photo: Erin Young, Fluid Solutions



# Site 25



## SITE 25 POST-MONSOON

No pipe was exposed at this site following the monsoon rains, September 9, 2010. Photo: FEMA

## SITE 25 DRAINAGE ASSESSMENT

Site 25 is located in the bend of the road at a major valley location. Upstream debris in the form of displaced soil and flowing rock were deposited at the upstream segment of this crossing. Downstream, the embankment and sideslopes have experienced significant erosion and rutting. Runoff continues to erode the downstream soils to find a point of equilibrium that has yet to be achieved, but is still very rocky in nature.

## SITE 25 DAMAGE ASSESSMENT

**Damage Assessment:** Moderate

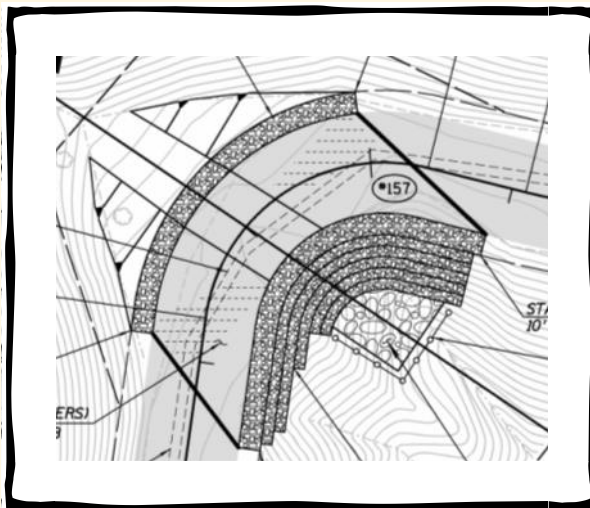
**Nature of Damage:** Erosion over the inside curve and downslope at a major valley location

**Pipe Condition:** No damage or exposure

**Lost Material:** About 70 cu yds aggregate debris on upslope side; 740 cu yds lost down slope

**Mass Wasting Character:** Displaced soil and flowing rock

**Hunter/Jacobs Mitigation Design:** Minor Drainage Crossing Repair



## DRAINAGE EVENT DESIGN

$D_{10} = 37$  cfs

$D_{25} = 48$  cfs

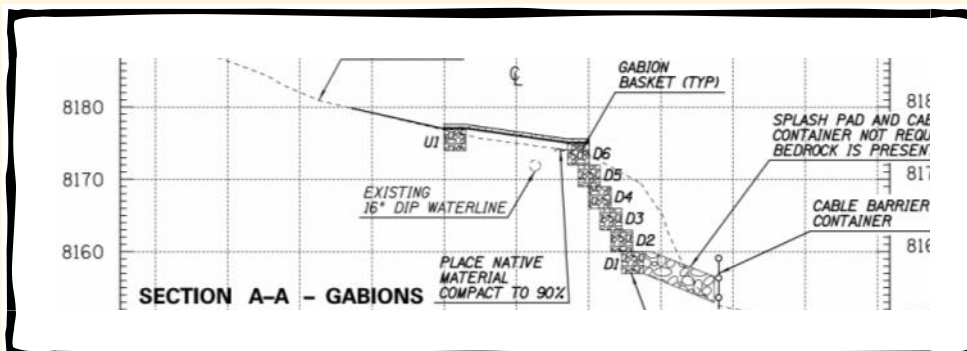
$D_{50} = 56$  cfs



## SITE 25 FINAL CONSTRUCTION

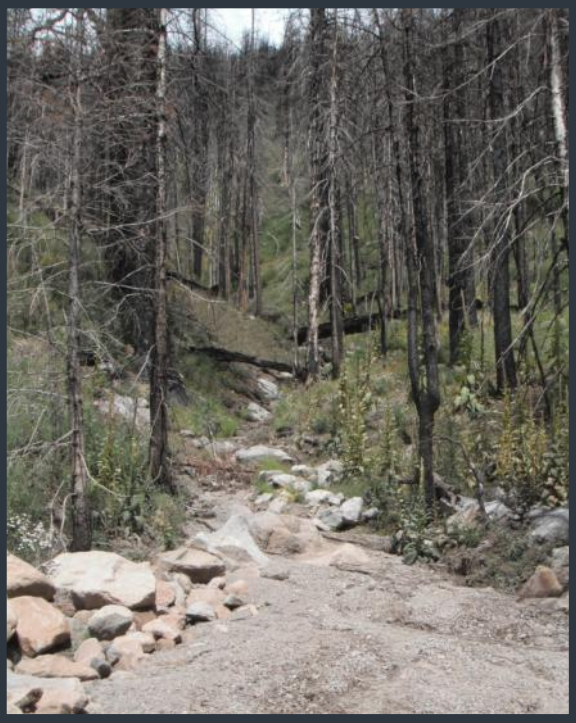
Newly finished road and gabion structure, September 27, 2012.

Photo: Tom Alexander Photography





# Site 26



## SITE 26 FINAL CONSTRUCTION

View looking up drainage on September 6, 2012.  
Photo: Erin Young, Fluid Solutions



## SITE 26 FINAL CONSTRUCTION

Completed road and gabion structure, September 27, 2012.  
Photo: Tom Alexander Photography

## SITE 26 DAMAGE ASSESSMENT

**Damage Assessment:** Moderate

**Nature of Damage:** Erosion of inside curve and downslope at a major valley location

**Pipe Condition:** No damage or exposure

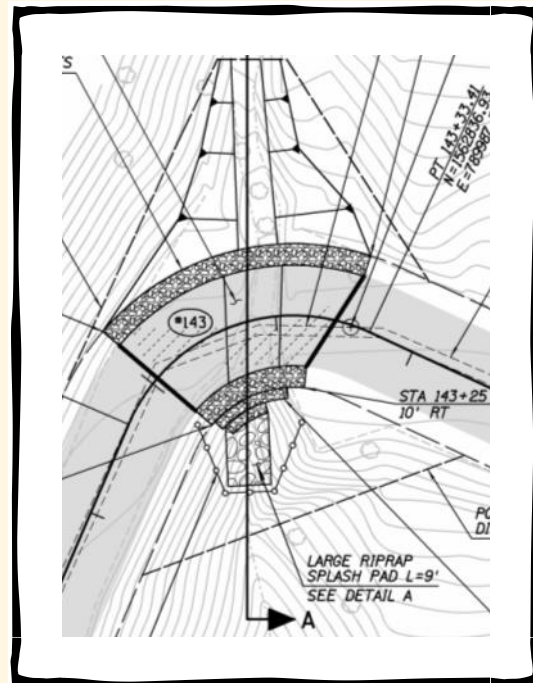
**Lost Material:** 70 cu yds aggregate debris on upslope side; 925 cu yds lost down slope

**Mass Wasting Character:** Displaced soil and flowing rock

**Hunter/Jacobs Mitigation Design:** Minor Drainage Crossing Repair

## SITE 26 DRAINAGE ASSESSMENT

The grade of the drainage is fairly flat upstream of the roadway, but steep downstream. The roadway appears to have been acting as a form of grade control structure for the stream. Upstream debris in the form of displaced soil and flowing rock are depositing at the upstream segment of this crossing. Downstream, the embankment and sideslopes have experienced significant erosion and rutting. Runoff continues to erode the downstream soils to find a point of equilibrium that has yet to be achieved, but is still

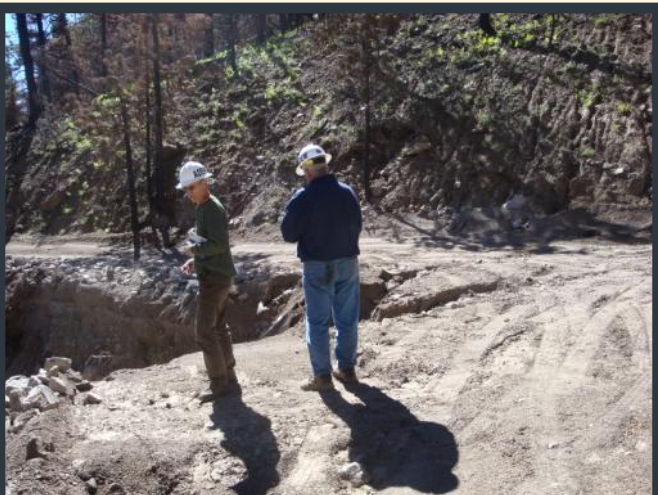


## DRAINAGE EVENT DESIGN

$D_{10} = 99 \text{ cfs}$

$D_{25} = 131 \text{ cfs}$

$D_{50} = 155 \text{ cfs}$



## SITE 26 POST-MONSOON

Erosion and rutting of the road surface with heavy erosion downstream, September 9, 2010. Photo: FEMA

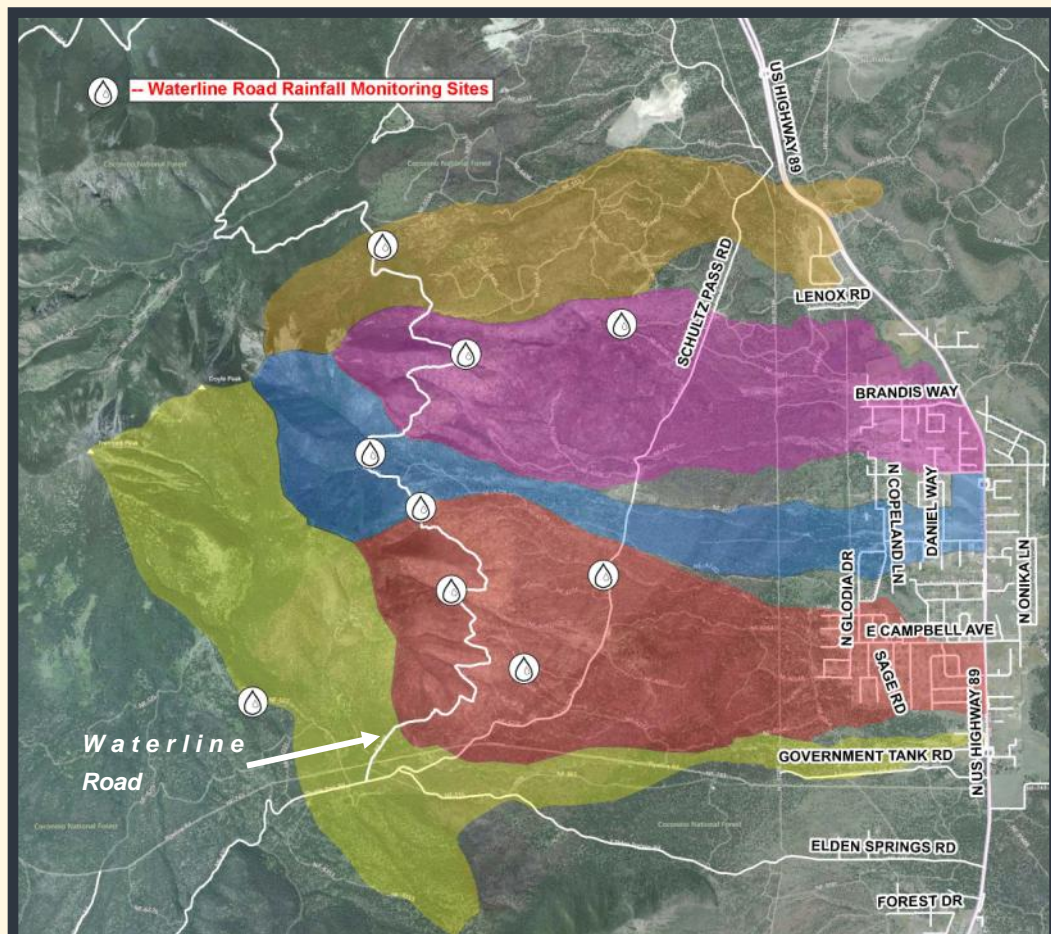


## Future Monitoring

Based on information from other burned forests in the southwestern United States, erosion and increased drainage flows can be expected for 10-20 years following an event. The City of Flagstaff has evaluated several methods for estimating the magnitude of a flooding event in order to determine if damage to the road crossings should be covered by the contractor's guarantee of withstanding a 50-year flood event.

The City of Flagstaff Utilities Stormwater Section evaluated several instrumentation options for recording and determining flow across the reconstructed road crossings. Options to directly measure flow itself, or indirectly using methods that involve constriction of flow, such as a weir or a flume, or installation of a radar device, were ruled out because the high velocity, sediment-laden flows that are of most interest would likely damage any instrumentation installed at the road crossings. Therefore, it was determined that rainfall would be the most accurate measure to correlate with flood event magnitude.

A network of nine rain gauges located on the eastern side of the San Francisco Peaks will be used to infer flood magnitude across Waterline Road. Seven of the rain gauges were installed by the Arizona Department of Water Resources following the Schultz Fire. The data from these gauges is received in real-time at Flagstaff City Hall and is automatically stored in a database, so there is a complete and accessible rainfall record for these sites. The gauges are currently maintained by Coconino County. The City, however, has the necessary equipment to maintain these sites should the County relinquish this effort. In October, 2012, the City of Flagstaff installed two additional rain gauges that are equipped with data loggers. These were installed after the Utilities Stormwater Section evaluated the existing network and its capacity to capture storm intensity across the area of concern.



### RAIN GAUGE LOCATIONS

Data from the rain gauges shown above can be used to infer return period using the NOAA 14 Atlas Point Precipitation Frequency Estimates program



The National Oceanic and Atmospheric Administration's *NOAA Atlas 14 Point Precipitation Frequency Estimates for Arizona* can be used to determine the return period for a given rainfall. This atlas is available as a web-based application at this location: [http://hdsc.nws.noaa.gov/hdsc/pfds/pfds\\_map\\_cont.html?bkmrk=az](http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=az). Each site will have slightly different rainfall values associated with it, depending on its location and elevation. Also, additional information on the timing, position and magnitude of any storm can be obtained from the National Weather Service's WSR-88Ds Doppler Radar data, which is archived and available at this web site: <http://www.ncdc.noaa.gov/nexradinv/>.

#### *City of Flagstaff Real-Time Rain Gauge Network*

<http://www.decdatasystems.net/Flagstaff/rainfallmapfs1440m.html>

*City of Flagstaff, Utilities Division,  
Stormwater Section, Tom Hieb*



#### **INNER BASIN RAIN GAUGE**

Nine rain gauges have been installed on the eastern slopes of the San Francisco Peaks since the Schultz Fire in 2010. These gauges (one shown above) are monitored by the City's BEAR team (at left). Photos: Tom Hieb, City of Flagstaff



## **REFERENCES**

2012 City of Flagstaff Report to the Water Commission, City of Flagstaff, Utilities Division.

Arizona Geological Survey, 2010; Youberg, A.; Koestner, K; Neary, D.G. 2010, Wildfire, rain, and floods: A case study of the June 2010 Schultz wildfire, Flagstaff, Arizona. Arizona Geological Survey Newsletter. Volume 40, No. 3, 5 p.

Hunter/Jacobs, 2012, Final Design Concept Report/Project Guidelines, Schultz Inner Basin Pipeline Reconstruction Project, March 20, 2012, City of Flagstaff: Phoenix, Arizona, report prepared for the City of Flagstaff, 127 p.

Inner Basin Aquifer Report, 1974; Harshbarger and Associates & John Carollo Engineers, Inner Basin Aquifer Report, City of Flagstaff, Arizona: Tucson, Arizona, Harshbarger and Associates, and John Carollo Engineers report prepared for the City of Flagstaff, 85 p.

Inner Basin Yield Study, 1983; HDR, Inner Basin Yield Study & Inner Basin Electrification and Well Retrofit Study, City of Flagstaff, Arizona: HDR report prepared for the City of Flagstaff, 81 p.

Jacobs Engineering Group Inc., 2012, Historic resources evaluation for the Schultz Flooding Inner Basin Road & pipeline reconstruction project, Coconino National Forest, Coconino County, Arizona: Flagstaff, Arizona, Jacobs Engineering Group Inc. report prepared for the City of Flagstaff, 32 p.

USGS-OFR 2012-1018; Macy, J.P., Amoroso, L., Kennedy, J., and Unema, J., 2012, Depth of cinder deposits and water-storage capacity at Cinder Lake, Coconino County, Arizona: U.S. Geological Survey Open-File Report 2012-1018, 20 p.

USGS Fact Sheet 017-01; Priest, S.S., Duffield, W.A., Malis-Clark, K., Hendley, J.W. II, and Stauffer, P.H., 2001, The San Francisco Volcanic Field, Arizona: U.S. Geological Survey Fact Sheet 017-01, 2 p.

#### **Acknowledgements:**

This book was prepared and compiled by Erin M. Young, R.G., Fluid Solutions. The following people are recognized for their extended review and contributions: Brad Hill, Mark Richardson, Stacey Brechler-Knaggs, Tim Harrington, and Robb Krause, all with the City of Flagstaff, and Marybeth Bunker, Shephard-Wesnitzer, Inc.





## Projects Made Possible Through These Partnerships



**FEMA**



ENERGY TRANSFER  
**Transwestern Pipeline Company**

## Pipeline Reconstruction & Relocation Core Team

### CITY OF FLAGSTAFF

Kevin Burke, City Manager  
Josh Copley, Deputy City Manager  
Brad Hill, R.G., Utilities Director  
Barbara Goodrich, Management Services Director

Rick Tadder, Finance Director  
Mark Richardson, Water Production Manager  
Stacey Brechler-Knaggs, Grants Manager  
Randy Pellatz, P.E., & Jim Wine, Retired

### DESIGN-BUILD TEAM

#### HUNTER CONTRACTING CO.

Terry Snyder, Program Director  
Chuck Lumer, Construction Manager

#### JACOBS ENGINEERING

Berwyn Wilbrink, P.E., Transportation Group Manager  
John "Pat" Fyie, P.E., Sr. Project Engineer

### INSPECTION SERVICES

#### SHEPHARD-WESNITZER, INC.

Guillermo Cortes, P.E., Project Principal  
David Monihan, P.E., Senior Project Engineer  
Doyle Corbus, Senior Inspector



701 North Cooper Road  
Gilbert, Arizona 85233  
P: 480.892.0521  
[www.huntercontracting.com](http://www.huntercontracting.com)



**Shephard Wesnitzer, Inc.**  
*Engineering an environment of excellence*

110 West Dale Avenue  
Flagstaff, Arizona 86001  
P: 928.773.0354  
[www.swiaz.com](http://www.swiaz.com)



101 North First Avenue, Suite 3100  
Phoenix, Arizona 85003  
P: 602.253.1200  
[www.jacobs.com](http://www.jacobs.com)